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EXPLORING THE POTENTIAL OF VR GAMES AS EXERCISE

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ABSTRACT

The technology behind virtual reality has achieved the point that anyone can buy the equipment for themselves to use at home. The world-wide pandemic in 2020 has forced people to stay home and avoid public places. Pandemic restrictions provide the opportunity for novel ways to exercise. One way is to play exergames.

This thesis discusses how different genres of VR games vary in the sense of perceived and observed exercise intensity and self-reported motivation. Participants' willingness to play and to recommend VR games as a form of an exercise is studied. This thesis also discusses the conflicts between the physical and virtual worlds and how those influence the player experience when playing VR games.

A mixed methods study was conducted. Nine participants' heart rates were detected during the game sessions as well as their motion data from a head-mounted display and controllers. Notes were taken from the game sessions, and game sessions were also recorded. Thematic analysis was made based on the notes and video recordings. Nine participants played two games each, which were *Half-life: Alyx*, *Portal Stories: VR*, *The Elder Scrolls V: Skyrim VR* and *Dance Collider*. The games were played with HTC Vive VR equipment. After the game session, participants answered a survey.

Participants had the most movements and highest heart rate curves during *Dance Collider* game sessions compared to the other three games. Women had more movements, and their heart rate increased more than men's. Results from the thematic analysis showed a similar trend. Women participants especially felt that they got sweaty and their heart rate increased while playing *Dance Collider*. Thematic analysis reveals that all the participants enjoyed the game sessions. Answers from the survey show the same result, and fun was the highest rated motivational reason for participants to play VR games. Additionally, this study reveals that exercise was not a very highly rated motivational reason for playing VR games. Survey answers show that participants rather recommend VR exergames for others than play those themselves. Thematic analysis revealed interesting gender differences, and only women participant expressed excitement as well as also low self competence. Some participants were affected by a conflict between the virtual and physical worlds. Three participants collided with real world objects by accidentally touching something. One participant thought that she would not dare to play with VR equipment alone because she can not see her surroundings.

Due to the low number of participants these results can not be generalized. The gender differences could be a theme for future work.

Keywords: exergames, virtual reality, HTC Vive, Half-life: Alyx, The Elder Scrolls V: Skyrim VR, Portal Stories: VR, Dance Collider, gender difference, player tracking

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TIIVISTELMÄ

Virtuaalitodellisuuspelit ovat teknologialtaan saavuttaneet sen pisteen, että niistä voi nauttia kuka tahansa kotonaan. Tänä keväänä (2020) ihmiset ympäri maailman viettävät enemmän aikaa kotonaan maailman laajuisen pandemian vuoksi. Rajoitukset ovat avanneet ovia uudenlaisille liikkumismuodoille. Yksi näistä on liikkuminen virtuaalitodellisuuspelien parissa.

Tässä tutkielmassa käsitellään, kuinka eri tyylilajien virtuaalitodellisuuspelit eroavat koetun ja havaitun liikunnan voimakkuuden ja motivaation tasolla. Tutkielmassa myös vastataan kysymykseen, kuinka todennäköisesti koehenkilö pelaisi virtuaalitodellisuuspelejä liikuntamuotona. Lisäksi tutkitaan mahdollisia ristiriitoja todellisen ja virtuaalimaailman välillä, ja sitä kuinka ne vaikuttavat pelaajakokemukseen virtuaalitodellisuuspelejä pelatessa.

Tutkielma toteutettiin käyttäen useita menetelmiä. Yhdeksän koehenkilön syke mitattiin pelihetken aikana, pelihetket videokuvattiin, ja niistä tehtiin muistiinpanoja. Lisäksi mitattiin, paljonko virtuaalitodellisuuslasit ja ohjaimet liikkuivat pelihetken aikana. Videon ja muistiinpanojen pohjalta toteutettiin temaattinen analyysi. Koehenkilöt pelasivat kukin kahta eri peliä. Pelatut pelit olivat *Half-life: Alyx, Portal Stories: VR, The Elder Scrolls V: Skyrim VR* ja *Dance Collider*. Pelit pelattiin HTC Viven virtuaalitodellisuuslaitteistolla. Pelihetken päätyttyä koehenkilöt vastasit kyselyyn.

Eniten koehenkilöt liikkuivat pelatessaan *Dance Collider* -peliä, jonka aikana myös heidän sykkeensä nousivat enemmän kuin muita pelejä pelatessa. Naiset liikkuivat miehiä enemmän, ja heidän sykkeensä nousivat enemmän. Temaattinen analyysi puoltaa sykkeestä ja liikkeestä saatuja tuloksia, sillä erityisesti naiskoehenkilöt kokivat hikoilevansa ja sykkeensä nousevan, kun he pelasivat *Dance Collider* -peliä. Temaattinen analyysi osoittaa, että kaikki koehenkilöt nauttivat pelihetkistä, ja kyselyn tuloksista käy ilmi, että eniten koehenkilöitä motivoi pelaamaan pelien hauskuus. Temaattisesta analyysistä paljastuu, että vain naiset kokivat positiivista jännitystä pelihetkissään, mutta myös vain naiset kokivat olevansa huonoja peleissä, joita pelasivat. Liikunta ei juurikaan motivoi koehenkilöitä pelaamaan virtuaalitodellisuuspelejä, ja koehenkilöt ennemminkin suosittelisivat sitä liikuntamuotona muille. Temaattisesta analyysistä havaitaan, että koehenkilöt kokivat ristiriidan todellisen ja virtuaalimaailman välillä. Näistä kolme osuivat pelihetkellä kattoon, sohvaan ja televisioon. Eräs koehenkilö koki pelottavana sen, ettei nähnyt ympärilleen.

Vähäisen osallistujamäärän vuoksi tämän tutkielman havaintoja ei voida yleistää. Tulevaisuudessa voitaisiin tutkia sukupuolten välisiä eroja mielipiteissä ja käyttäytymisessä virtuaalipelejä pelatessa.

Avainsanat: liikuntapelit, virtuaalitodellisuus, HTC Vive, Half-life: Alyx, The Elder Scrolls V: Skyrim VR, Portal Stories: VR, Dance Collider, sukupuolierot, pelaajan seuranta

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FOREWORD

This thesis has been a huge learning process for me. I feel that my academic vocabulary has expanded which has a great effect on my writing skills. I also learned a new and interesting qualitative analysis method, thematic analysis. Even it has been hard from time to time, I enjoyed doing the research. I enjoyed especially to go through the data gathered from the evaluations. The worldwide pandemic and the restrictions forced me to change the evaluation plan. Although, I was able to adapt to a new evaluation plan, not once but twice.

I would first like to thank my friends and family for cheering me up and encouraging me when I have had doubts. I am very thankful for the participants of this study, without them this would not be possible. My special thanks go to my supervisor, Paula Alavesa. Without her, I would not be able to finish this work with so strict time limit. She helped to tackle the obstacles caused by the pandemic restrictions. She also has a contagious positive attitude which helped me to work with this thesis. I want also to thank my supervisors Katherine Mimnaugh and Markku Suomalainen, I really appreciate the effort they have given to this work.

Oulu, June 16th, 2020

Oona Kivelä

LIST OF ABBREVIATIONS AND SYMBOLS

CSV	Comma-separated values
HMD	Head-mounted display
HR	Heart rate
HRM	Heart rate monitor
IMU	Inertial measurement unit
PA	Physical activity
RQ	Research question
SSQ	Simulator Sickness Questionnaire
VR	Virtual reality
WHO	World Health Organization

1. INTRODUCTION

In recent years, virtual reality (VR) has become more commercial and available for consumers. It is not unusual to have VR equipment at home. VR has a long history. It began in the 1950's when Heilig introduced his idea of the Sensorama apparatus [1]. Besides the 3-dimensional sight, a Sensorama also stimulated the sense of smell by providing odors from the apparatus. The modern head-mounted display (HMD) was first introduced by Sutherland in the late 1960's [2]. The first modern hand controller for VR was DataGlove [3]. VR technology tried to break through in the early 1990's but the simulator sickness symptoms were too hard to tackle back then [4]. Simulator sickness, or cybersickness, has been studied a lot. It plays a crucial role, especially when developing something new into the VR environment. There are quite a few common symptoms in cybersickness, and for example, nausea and headache are two of those [5]. One explanation for cybersickness is the so-called Sensory Conflict theory, where one's senses run into a conflict.

In 2016 Oculus Rift broke through the market and soon after came HTC Vive as well [6, 7]. Today the technology is at the level that the equipment is comfortable to use. The current VR set includes controllers for both hands, an HMD, and a computer that runs the games [8]. There are VR setups with and without player position tracking base stations. There are also wired and wireless sets available.

People around the globe are now spending more time at home than ever due to the current COVID-19 pandemic. Self-isolation provides great opportunities for more people to use VR applications. Traveling restrictions do not matter when one can travel to see the world's seven wonders from their living room couch. Even during social distancing, many games offer a multiplayer option. Compared to a home training video, exercising by playing a VR game can be more fun when you can collect points and achieve new levels. The market for novel ideas in the scope of VR and other console games is now open.

The biggest VR providers offer open-source libraries for developers [9, 10, 11, 12, 13, 14, 15]. They also provide a wide and helpful community. These communities not only offer support and forum sites, but also tutorials from newbies to more advanced developers. Player tracking is highly connected to game development, and it is a useful tool for marketing and research as well. Player tracking can be called game analytics, which has a wider meaning. To track the player while playing an exergame, useful metrics are, for example, the length of a game session, the position tracking of the HMD and controllers, the number of calories that the player burned, and the music tracks that a player chooses [16, 8].

Games whose outcome is determined by physical effort are exertion games or exergames [17]. In other words, exergames are a combination of exercise and video games. Exercise, or physical activity, is any type of bodily movement which is produced by using the skeletal muscles [18]. Besides the exergames, VR offers a platform for other serious games as well. Serious games are games that are educational or in some other way beneficial [19]. This study focuses on VR games and exergames and those with potential to be used for exercise purposes.

1.1. Research Questions and Methods

This thesis has three main foci. First, the exercise aspects while playing VR games are examined. Second, opinions of exercising with VR are studied. Third, the conflicts between the real and virtual worlds are observed. This thesis aims to answer the following research questions (RQ):

- RQ1: How do different genres of VR games vary in the sense of perceived and observed exercise intensity and self-reported motivation?
- RQ2: How likely are users to play VR games as a form of exercise?
- RQ3: What conflicts are there between physical and virtual environments, and how do they influence the player experience in VR games?

To answer all of the above questions, mixed methods are used. Nine people participated in this study, five men and four women. Two male participants had VR equipment at home. The average age of the participants was 31. Participants were asked to play two different VR games each. The games that were used are *Half-life: Alyx*, *The Elder Scrolls V: Skyrim VR*, *Portal Stories: VR* and *Dance Collider*. Informed consent was asked before participation. Participants' game sessions were recorded and observed. All comments from the videos were transcribed, and thorough thematic analysis was done from the video recordings of game sessions. From each game session, motion data was collected from the VR controllers and the HMD. Participants' heart rate data was collected before and during the game session. Motion and heart rate data was compared between games and participants. Finally, the participant answered a survey about exercising with VR. Survey data was analyzed thoroughly to find out what motivates them to play VR games and to compare the participants' backgrounds. A previous study from the author was used as a pilot study [20]. In that study, participants' motion and heart rate data were measured while they played two different VR games.

Unfortunately, the pandemic also changed this thesis evaluation plan twice, but in the end, the result is even better this way. The restriction caused by the pandemic started just before the evaluation was supposed to start. Restrictions forced the author to find another way to perform the tests. To be safe, only the people who the author had seen during pandemic restrictions were asked to participate. The test setup was at the author's home. Due to the low number of participants, a more qualitative point of view was chosen.

1.2. Author's Contribution

The author's main responsibilities were to create the survey, implement a motion data analyzer, find the participants, design and set up a testing environment, guide the participants through the test, document the test situation, analyze the data and write this thesis. The thesis supervisor acted as a second observer for the qualitative thematic analysis made from the test situation. Fellow student Toni Kuosmanen helped with creating a motion tracking script.

1.3. Structure of This Thesis

First is an introduction with the literature background of VR, exergames, and player tracking. Then the design of this study is explained in detail. The implementation for this study is presented next. Then, results gathered from the study are presented, followed by the discussion of the results. Conclusions are presented in the Summary chapter.

2. BACKGROUND

The background section introduces the literature review for this thesis. This section starts with the definition of virtual reality and it's current state and history. Then exergames are defined and introduced, and how exergames are linked to virtual reality games. Lastly, player tracking is introduced.

2.1. Virtual Reality

Steuer [21] has defined virtual reality (VR) from a human perspective and from a technological point of view. From a human perspective, VR is defined by the concept of presence. Slater and Wilbur [22] have studied the term presence in the context of virtual environment. Slater and Wilbur gives the explanation to a term presence that "presence is a state of consciousness that may be concomitant with immersion, and is related to a sense of being in a place" [22]. From a technological perspective, VR is an electronically simulated environment that is accessed by a user with a head-mounted display (HMD) and controllers. Technology today enables players to enjoy VR environments.

2.1.1. Gender Differences in VR

Women and men are not just physically different, but boys and girls are even raised differently [23]. The habits and values that are learned in childhood affect humans' later experiences in life as well. Felfnhofer *et al.* [24] investigated whether there is a gender gap in presence experiences. They found that men generally perceived a higher sense of spatial presence than women. Munafo *et al.* [25] studied gender difference in experiencing cybersickness. According to their study, it seems that the prevalence of cybersickness is greater among women than among men. In a more recent study from Peck *et al.* [26] the earlier observed gender difference in cybersickness have been proven wrong. Meta-analysis made from a collection of studies show that a lot of studies that states the gender difference in cybersickness have had a bias sample of participants. In those studies, the gender distribution have been uneven.

2.1.2. VR Hardware

Current VR equipment minimally includes a computer, an HMD, and hand controllers. Because vision is the dominant sense, the role of the HMD is crucial for creating the feeling of immersion. According to Slater and Wilbur [22] the immersion is a description of a technology which enables an illusion of reality to human senses. Sometimes an HMD may also include headphones for providing sound. An inertial measurement unit (IMU) is the technology that allows the devices to track the position of the HMD by the IMU's gyroscope, accelerometer, and sometimes also magnetometer. The IMU is one of the most important technologies enabling current VR. Another enabling technology is digital cameras, which enable tracking of the eyes,

the head, the hands, and the entire human body. Infrared offers a good option for tracking cameras since the human eye does not detect its spectrum. Computers are also a very important part of the VR equipment. Communication between the computer and the headset is many times done by wires but not always; for example, Oculus Quest does not require wires. [8 p.47-48]

In Figure 1, 2 and 3 are examples of three different sets of VR equipment available on the market. The Oculus Quest has the easiest setup since it can be used with just an HMD and hand controllers [12], while PlayStation VR requires precision tracking and a camera with an HMD and controllers [27]. The HTC Vive has base stations with an HMD and hand controllers [28].

Figure 1. Oculus Quest set has an HMD and two hand controllers. (Figure with permission [29])

Figure 2. HTC Vive set includes two base stations, two hand controllers, and an HMD. (Figure (c) Author)

Figure 3. HMD for PlayStation VR. (Figure public domain [30])

2.1.3. Community for Developers

The community behind VR offers open-source libraries for developers, for example, Google [9], OSVR [10], Valve Software's OpenVR [11], Oculus' developer center [12], and SteamVR Developers [13]. All of these sites offer open libraries for developers, as well as support, guidance, and community for asking questions and sharing thoughts. Commonly used tools are also freely available, such as Unity [14] and Blender [15]. Both of these also provide help and support, and a number of tutorials. Unity and Blender have also a lot of ready-made things, so not everything needs to be implemented from scratch.

2.1.4. Cybersickness in VR

In recent years, cybersickness symptoms in VR have been a hot topic. It is an especially important topic when developing something new for a VR environment. One theory is the Sensory Conflict Theory, which postulates that the user's senses run into conflict with each other. For example, one walks in the VR world but is standing still in the real-world [31]. A widely used tool for measuring cybersickness is the Simulator Sickness Questionnaire (SSQ) from Kennedy *et al.* [5]. The common cybersickness symptoms which are measured in the SSQ are general discomfort, fatigue, increased salivation, nausea, burping, difficulty focusing, sweating, difficulty concentrating, stomach awareness, headache, eyestrain, blurred vision, fullness of head, dizziness with open and closed eyes, and vertigo.

2.2. History of VR Adoption

The history of VR research began in the 1960's when Morton Heilig [1] patented his Sensorama apparatus (Figure 4). Sensorama was a multisense device where the user was seated to watches a movie. The apparatus included a wide vision and stereo-surround sound. While the user watched the movie, they felt the wind either only on their head like driving a roofless car or on their whole body like driving a motorcycle. The Sensorama also included multiple odors to simulate the sense of smell. The user

was seated in the apparatus and the seat vibrated in order to simulate movements. Heilig first introduced his idea about the Sensorama in 1955 as a multi-sensory theater experience [32].

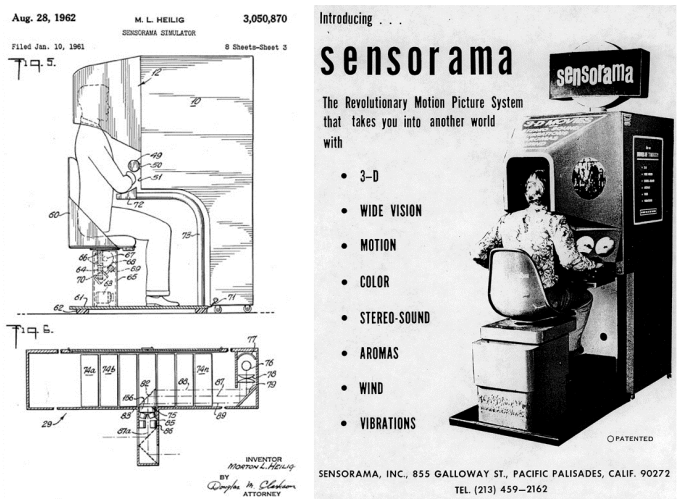

Figure 4. Heilig's Sensorama apparatus. [32]

Heilig first introduced the idea of Sensorama in the 1950's, but before he was able to build the first prototype he patented the Telesphere Mask [33]. The Telesphere Mask was a stereoscopic-television apparatus for individual use (Figure 5). Heilig's Telesphere Mask was the first HMD. In 1965 Ivan Sutherland [2] published The Ultimate Display, where he introduced an idea to override the user's senses by computer. A few years later Sutherland [34] introduced the HMD optics with miniature cathode-ray tubes (CRT) (Figure 6). In Sutherland's HMD, the idea was to make an illusion so that the user saw three-dimensional images. The three-dimensional images had to move and change similarly as they would in the real world.

Figure 5. Heilig's Telesphere Mask. [33]

The next step in the history of VR was Myron Krueger's experiments with responsive environments in the 1970's [35]. He was a part of a research group that combined art and technology in a project called GLOWFLOW. In a GLOWFLOW, the viewer

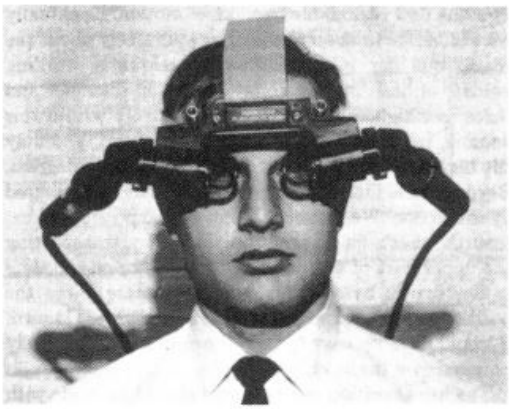

Figure 6. Sutherland's HMD optics with CRTs. [34]

entered a darkened room which had glowing lines creating an illusion of space. Having opening questions about the GLOWFLOW, Krueger continued his studies with responsive environments with the METAPLAY project. METAPLAY had two rooms connected (Figure 7). In one room was the participant, and in another was an artist. The participants saw themselves and whatever the artist drew as a reflection on the wall.

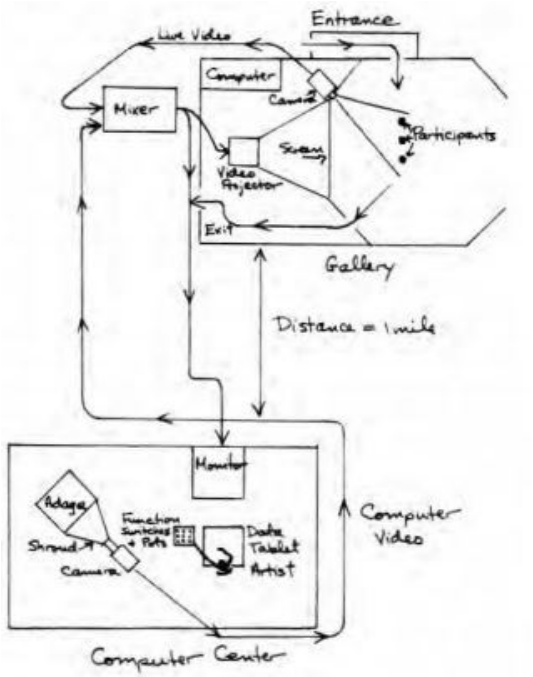

Figure 7. Communications of METAPLAY. [35]

In 1987, a research group lead by Jaron Lanier designed and built a DataGlove (Figure 8) [3]. It was the first step for creating a modern hand controller for VR. DataGlove was a hand-to-machine interface device. It sent real-time position and orientation information to the computer. It included analog flex sensors that measured finger bending motions. Ultrasonics and magnetic flux sensors were used to measure hand position and orientation. Sensors in DataGlove were mounted on the glove, which was connected to the driving hardware by small cable.

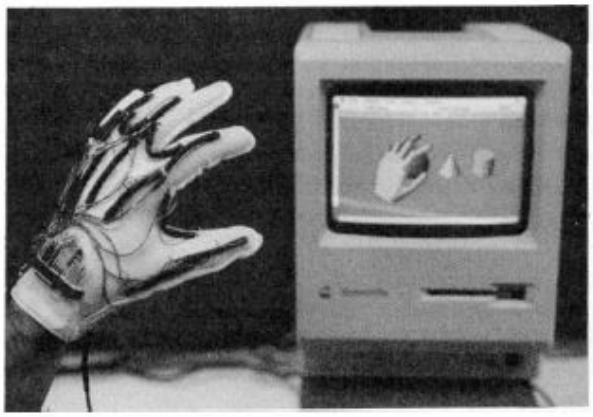

Figure 8. DataGlove without outer glove in order to show sensors. [3]

In 1992, Cruz-Neira et al. [36] introduced the Cave Automatic Virtual Environment (CAVE). It was a cube-shaped room. CAVE systems had speakers in the corners providing a sound environment. On each face of the cube, there were projection screens, except on one side, where users could easily get in and out of the CAVE. The user was detected via 3D glasses which had sensors to track the location and movement of the user. This way, the screen projection could be changed while the user moved. CAVEs are still to this day used for accessing VR collaboratively from one space (Figure 9).

Figure 9. CAVEs are still in use as an collaborative entry for VR. (Figure with permission [37])

For Christmas 1993, Sega was supposed to release the first consumer VR headset [4]. The headset had minor issues about its weight and comfort, but it was still able to deliver VR with immersive 360-degree environments and fast-paced gameplay. By that time, sensor technology was very expensive and in order to have a customer-

friendly price for the Sega VR, they used sensor technology from a company called Ono-Sendai. Ono-Sendai's head tracking solution was a combination of an azimuthal sensor, which was created with a magnetometer, and a photodetector system which included a small sphere that was filled with liquid and gas and attached with LED and light sensors. Movements were detected by how the LED light passed through the sphere's gas and liquid environments. Orientation was detected by an azimuthal sensor that used Earth's magnetic field and a photodetector that determined the degree of tilt. Sega VR also had an in-built stereo sound system. Unfortunately, Sega VR did not get released. Test groups had critical issues with nausea and motion sickness.

At the same time, Nintendo was implementing its own VR game console; Virtual Boy [38]. The Virtual Boy was unveiled in November 1994. The Virtual Boy had a unique tripod-mounted unit that required players to immerse themselves in the dual-screen display. The creators hoped that it would be the next big thing, but commercial reviewers had several problems with it. These problems included that it made users feel headache, eye strain, and dizziness, that it only showed red and black colors since red LEDs were the cheapest ones, and of course that it had a high price.

In the 21st century, there has been a lot of VR research due to the rapid evolution of the technology. Oculus Rift's first prototype was designed by Palmer Luckey in 2012. The final outcome was released in March 2016 [6]. The Oculus Rift has good competition from the HTC Vive. Valve and HTC were developing their own VR systems at the same time as Oculus in 2012. Valve was not planning to build its hardware, so it first tried to have cooperation with Oculus but later on, they made a deal with HTC [7].

2.3. Exergames

VR playing as an exercise form is the main focus of this thesis. This thesis studies the perceived and observed exercise intensity while participants play the VR game. Additionally, the study focuses on the motivational aspects for one to play the VR games. Games from different genres are studied, not just games which are expected to be exergames.

The term exergame has been used to describe the combination of exercise and video games. According to Hagger and Chatzisarantis [39], exercise is a form of physical activity where a person wants to use energy for health reasons. Florian Müeller *et al.* [17] define an exertion game as a digital game where the outcome of the game is determined by physical effort. Müeller *et al.* points out that exergames are more than just bodily movement. When designing an exergame, one should also understand the technological challenges of digitally capturing, interpreting, and communicating exertion. Exergames are any type of video game or multimedia interactions that require the player to physically move in order to play. Oh and Yang [40] in their study have found many synonyms for exergames, such as exertainment, dance simulation video games, interactive video games, activity promoting video games, physical gaming, (kin)aesthetic video game, and physical activity-change game.

In 2011, Bailey and McInnis [41] conducted a comparison study where they observed motivation and metabolic equivalent tasks of children who exercised either via treadmill walking (3 mph) or via six different exergames. Children enjoyed more

exercising via exergames than by treadmill walking. Enjoyment was highest for children with the highest BMI percentiles. Maddison *et al.* [42] in 2007 conducted a study where they investigated the health benefits of playing active console games. They measured heart rate, oxygen consumption and physical activation in real-time. They concluded that playing active console video games is similar in intensity as light traditional physical activities such as walking, skipping, and jogging.

One of the gaming consoles Bailey and McInnis used in their study was the Nintendo Wii. It was later used in a study from Staiano *et al.* [43] in 2013, where their participants were also children. Staiano *et al.* had three different groups. Group one played Nintendo Wii with a partner every school day, and their goal was to collect points together by expending calories. Group two also played Nintendo Wii with a partner every school day, but they played against each other. Group three was a control group that continued their daily lives. The study lasted 20 weeks. During these 20 weeks, children who played exergames lost weight. The study also revealed that cooperation increased peer support, self-esteem, and self-efficacy. Staiano *et al.* state that exergames can be used to battle childhood obesity.

2.3.1. VR Exergames

VR games have a high potential to be used as an exercise method. Games require a player to interact via movements in order to proceed in the game. There are different types of games; some require the user to move one's whole body and in other games, it is enough to just make slight movements with hands while playing seated. One concern is that players will get under- or over-exerted while playing VR exergames. Too intense exercise starting from scratch may lead to injuries. There is a study, conducted by Yoo *et al.* [44] in 2017, that is based on this concern. Most of these games lack personalized information about player's exertion level. Yoo *et al.* [44] designed a game that uses two different data sets, player's heart-rate and game performance. In this way, they were able to monitor the player's physical fitness.

As said before, not every VR game is suitable for exercising. In the author's previous study [20], two different types of VR games were compared by how much they increased the player's heart rate, and how much the player moved in total. Motions were tracked from HMD and controllers. There were significant differences in both, heart rate and movements, whether the player was playing *BeatSaber* or *QuiVR* game. In conclusion, the VR set offers a platform for different types of exercises, as in this study, the exercise a player gets can be aerobic or static exercise.

The worldwide COVID-19 pandemic offers for VR technology a great potential to provide fitness and exercise services for consumers at home in quarantine. The virus has not only broadened the markets for exergames, it has also provided an opportunity for new game ideas [45]. One well-known exergame, *BeatSaber*, has already been played for fitness purposes, but during self-isolation BeatSaber has additionally launched a new song called FitBeat [46]. As can be predicted from the name of the song, it is a fitness-focused track.

As described previously, exergames are combinations of exercise and video games. VR games require a player to interact with the game by moving the body. However, not all VR games are exergames. During exercise, the body goes through changes in

the immune system [47]. Physical activity also increases energy consumption [18] but many VR games can be played without any increase in energy consumption. Some games can be played seated, for example, *Solitaire VR*, which is a VR game but not an exergame.

2.3.2. Definition of Exercise

When speaking of exergames, it is important to explain what is meant by exercise. The term exercise does not cover every movement that is done with our bodies. Besides the physical changes that happen in the body while exercising, an exercise can also be defined as a movement with the goal to accomplish a new skill or fitness level.

Physical activity (PA) can be defined as any bodily movement which is produced by skeletal muscles, and which results in calorie consumption [18]. Hallal *et al.* [48] studied populations' physical activity in 2012. Their study used data from the World Health Organization (WHO), collected from all around the globe, and included people whose ages ranged from 15 years old to adults. Their criteria for physical activity were that the person exercised 30 minutes of moderate-intensity PA on at least five days every week, 20 minutes of vigorous-intensity PA on at least three days every week, or an equivalent combination achieving 600 metabolic equivalent minutes per week. The study revealed that almost every third adult (31,1%) are physically inactive. When the human body is under a prolonged and intensive endurance exercise, several changes are discovered in the immune system [47].

2.3.3. Gaming Habits

Playing video games can have a lot of benefits. They can be educational, social, and therapeutic. On the other hand, excessive video game playing can be addictive. Especially addictive video games are online games that never end or pause. Addiction to computers includes psychological and physical symptoms, such as the inability to stop the activity, craving more time, feeling empty, depressed, or irritable when not at the computer, lying, dry eyes, migraine headaches, backaches, or sleep disturbances [49]. In Finland 2008, 28 % of people aged 16 to 49 described themselves as active players. Male are twice likely to describe themselves as active players compared to females [50].

2.3.4. Serious Games

The term "serious game" is used for games that are educational or are in another way beneficial. Serious refers not only to education, but it is also used in the sense of study relating to matters of great interest or importance. Serious games can be used in many different areas to raise knowledge or conversation around a specific topic. Games offer a very unique and powerful storytelling nature. The hook in serious games is that they are entertaining and interactive. Using games for education purposes guarantees that the focus of the player is on the topic [19]. Schrader *et al.* [51] in 2017

studied players' emotional states during gameplay. To track players' emotions, face-recognition methods and players' in-game data can be used for analysis. Knowing players' emotions is useful for game design. It helps to detect the players' emotion in each part of the game and whether players' emotion is affecting useful or harmful to learning.

Zyda [52] defines a serious game is a game that includes story, art, and software, as well as pedagogy. Zyda states that pedagogy makes games serious. However, the entertainment component comes first and pedagogy follows. According to Stone [53], serious games are games with a purpose. The purpose is to learn and increase knowledge. Stone also points out that even with good pedagogy, the game may fail. The most important thing in the design of serious games is an understanding of human-centered design issues. VR has been used in serious games. It is very useful for case studies and training. VR serious games have been used especially for professional training purposes. The benefits of using games for training are that they are low-cost and freely-available software.

VR environments provide a potential platform for real-life situation training tools. Simulations are low-cost since they are implemented only once, but they can be used multiple times. In VR environments, the key components are that they are interactive and immersive, and that the brain does not see the difference from real-life. A study conducted by Farra *et al.* [54] had a VR disaster simulation, which effectiveness in disaster training was studied with nursing students. Their study revealed that the group which took the VR simulation, compared to the group which used traditional study methods, had better grades after two months trial. Heinrichs *et al.* [55] performed a study where the participants took a training with a VR simulation. Before the training, 18 % were confident to manage the simulated situation, and after training that number increased to 86 %.

2.4. Player Tracking

In human-computer interaction research (HCI), which is game user research, player tracking is measuring the different aspects of a players' activity. This is sometimes also called game analytics, although game analytics is a broader concept that also contains a number of installations, retention, and many more concepts [56]. Player tracking methods can be chosen based on the game the tracked player is going to play. According to Dachen *et al.* [16] useful gameplay metrics for exergames are, for example, session length, calories burned, chosen exercise, player accuracy in performing exercises, a match between exercises shown and player actions, total playtime over some number of days, player hardware or exercise equipment, player demographic, music tracks selected, backgrounds selected, avatar selection, power-ups or content unlocked, and the total duration of play per user. Useful gameplay metrics for adventure games are, for example, story progression, non-player character interaction, trajectory, puzzle completion, character progression, character item use, world item use, artificial intelligence enemy performance, and the damage that is taken and received.

2.4.1. Player Tracking in VR

Player tracking in VR is similar to any other game platform, but the extra dimension give player tracking in VR special characteristics. The nature of VR technology is that the user is immersed and interacts by physically moving oneself. One important player tracking method in VR experiments is to track the effect of cybersickness. One method for tracking the cybersickness is using psychometric questionnaires, such as the SSQ [5]. Other player tracking methods are, for example, to track the position of HMD and hand controllers [8 p.338-343].

2.4.2. Biometrics

Biometrics are biological measurements that can be measured from humans. They measure biological quantities or patterns, and also an individual's features that can be used in identification or authentication [57]. Jain *et al.* [58] describe biometrics as being any human physiological or behavioral characteristic which is universal to everyone, but unique for one person; permanent, meaning it is invariant with time and collectability, and measurable. In the context of identification and authentication, the most accurate data is achieved by collecting multiple biometrics. Voiceprint, infrared facial and hand vein thermograms, fingerprints, face, iris, ear, gait, keystroke dynamics, DNA, signature, odor, retinal scan, hand and finger geometry are biometrics used in the identification and authentication [58]. Biometrics is the practice of using sensors attached to the player's body in order to monitor one's bodily data [56].

3. DESIGN

The evaluation plan of this study changed a couple of times due to the pandemic caused by COVID-19 2020. The evaluation plan was incremental and guided by having to adapt to an unforeseen situation. In this chapter, alternative evaluation plans are presented at first, and then the final evaluation plan is presented including the methods, participants, and research questions. At the end of this chapter, the games that were used in the evaluation are presented.

3.1. Evaluation Plans A and B

Before the COVID-19 restrictions started, this study was supposed to be held in a public place, and participants were to be recruited on site. The used games were supposed to be the same as in a previous study by the author [20], BeatSaber, and QuiVR with two others from different genres. The number of participants was supposed to be high. However, the restrictions made us to give up on plan A.

The COVID-19 restrictions forced supervisors and author to come up with another evaluation plan, where participants could stay home and use their own VR equipment. To get people to participate, a participation gift was designed. Subjects would get the motion data capture program along with some data analyzer program for later use as well. The played games with this plan would have varied a lot. The number of participants was supposed to be high. Unfortunately, there were no answers for the survey after two weeks spreading the invitation to participate through social media sites LinkedIn and Facebook, the university's e-mail lists, forum sites Steam Community, Viveport, and Reddit. There were no reactions during the two weeks, so plan C was needed.

3.2. Evaluation Plan C

The final evaluation plan was to have participants play two different VR games at author's home. While they were playing, their HRs were detected. At the same time, their motion data was captured from hand controllers and an HMD. Participants were also video recorded. After the game session, they were asked to answer the survey. This evaluation setup was partly piloted in a previous research study by the author [20].

The step-by-step procedure for evaluation was as follows:

- The participant arrives and is seated. The heart rate monitor (HRM) is placed on the wrist and the HR measuring is started.
- The participant is told more about the study, and about the games which one can choose while waiting for their HR to calm down.
- Fitting the HTC Vive HMD on participant and making sure that it sits well.
- The participant stands up and navigates to the game via Steam VR, or the game is launched from the computer.

- The participant plays the introduction of the game, if available.
- The game session starts. The motion capture program and video recording are started. The participant now plays the game for at least 15 minutes.
- During the game session, notes are taken.
- The game session ends. The motion capture program is stopped.
- The participant now plays the second game of their choice. The participant again plays the introduction.
- The motion capture program is started again. The participant can now play the game for at least 15 minutes.
- The game session ends. The motion capture program is stopped. The HRM is taken off from the wrist.
- The participant's motion data is sent to a compressed file.
- The participant answers the survey. The compressed motion data is attached to the survey.

Before and after the game session, cookies, coffee and soda are offered to the participant.

3.2.1. Mixed Methods

Mixed methods are used in this study, both qualitative and quantitative material is gathered and analyzed for a holistic picture of gameplay. Motion data is captured from an HMD and controllers. HR data is gathered via a HRM. The participant is observed during the game sessions and is video recorded. Participants also answer a survey about exercising via VR games.

Participants' movements from the HTC Vive apparatus are captured while they are playing any VR game. Motion data is used to detect how much participants move during different game sessions. Motion data is captured via a capture program running parallel with the VR game.

Participants' HRs are detected by the HRM. The resting heart rate is measured before the actual game session while the participant is seated. HR is used to monitor the intensity of the game session. HR is measured with a Polar Ignite [59] HRM.

The game sessions are filmed by mobile phone and also observed during gameplay. Notes are taken while the participants are immersed in VR, so the typing did not disturb them. The exact comments from participants during the game sessions are checked from the video. The qualitative thematic analysis is made based on the comments and acts in the video. Survey data is used to gather background information, their thoughts about VR and exercising, and also their main motivation for playing such games.

3.2.2. Research Question

This study had three research questions and they are introduced in the Introduction. A thematic analysis made from notes and video material from the game sessions, survey, and measured biometrics provide answers for the RQ1. The survey will answer the RQ2. A thematic analysis made from notes and video material from the game sessions will provide an answer for the RQ3.

3.2.3. Participants

This study had nine participants, five men, and four women. Due to the restrictions caused by the COVID-19 pandemic in 2020, the participants were my close friends or their spouses. Participants were relaxed and at ease during the whole session. Participants represent both genders and they were aged between 26 to 38 years old. All participants were Finnish, and their comments were in Finnish. Three participants have a Master's degree, five participants have a Bachelor's degree, and one participant has a high school degree.

3.2.4. Introduction to the Used Games

The games that participant could choose from were *Half-life: Alyx*, *Dance Collider*, *The Elder Scrolls V: Skyrim VR* and *Portal Stories: VR*. All of these games have good ratings in the Steam store [60]. They are relatively well-known games so they should not have any significant technical issues. Detailed information of the games is in the Table 1.

The Elder Scrolls V: Skyrim VR was hit when it was published October 28th 2016. It was in the Steam's top 10 list in less than a day [61]. *The Elder Scrolls V: Skyrim VR* is still one of the most popular games in the Steam [62]. *The Elder Scrolls V: Skyrim VR* is a single-player open-world fantasy role playing game where a player completes quests and battles against enemies. The idea is to defeat Alduin the World-Eater dragon at the end of the game. The player can choose his role and develop role-specific skills. It is not necessary to play through and kill the dragon. The player can just develop the skills and create new characters with different roles. *The Elder Scrolls V: Skyrim VR* was chosen to be one of the games not only because it is popular in the Steam store but also because it is well-known and it has a long history as a PC game starting from 1994 when The Elder Scrolls: Arena was published [63].

Half-life: Alyx was chosen from the same reasons as *The Elder Scrolls Skyrim VR* to be used in this study. *Half-life* games have also been popular PC games [64]. *Half-life: Alyx* was released in March 2020. It is a first-person shooting game, where the player fights against an alien called Combine as Alyx Vance [64]. The story happens between *Half-life* and *Half-life 2*. The game got good reviews for its immersive experience. One specific game physics detail is that liquids are placed inside bottles and they act as liquid [65]. Half-life: Alyx has been one very popular game on the Steam store, and it is currently in the top 10 [62].

Portal Stories: VR was released for free in 2016 but it required the player to own *Portal 2* [66]. *Portal Stories: VR* is an adventure game that has 10 puzzles the player needs to solve. The player needs to solve his way out of the room. On one hand, a player has a teleportation device and in the other a retrieval tool for picking things and pressing buttons. [67]. *Portal Stories: VR* was chosen for this study for the same reason as the above two games.

Dance Collider is a casual sports game that can be described as "the ultimate VR dance game" [68] and it was chosen for this study to represent an exergame. As the name predicts the game is an arcade style dance and rhythm game. Nodes come towards the player and player needs to hit them with matching colored controller [69]. The harder a player hits, the more points he gets.

Steam is a game distributor, and it is founded by the Valve Corporation. It is a digital platform. Steam also provides VR games, which can be launched via SteamVR. [70]

Table 1. Games used in this study and their genres and amount of game sessions during the study.

Game	**Genre** [1]	**Sessions**	**Description of the game**[2]
Half-life: Alyx	Action, Adventure	4	The story of an impossible fight against a vicious alien race known as the Combine.
Dance Collider	Action, Casual, Indie, Sports	7	Intense arcade dance action for VR.
The Elder Scrolls V: Skyrim VR	Role playing game	4	Skyrim VR reimagines the complete epic fantasy masterpiece with an unparalleled sense of scale, depth, and immersion. From battling ancient dragons to exploring rugged mountains and more.
Portal Stories: VR	Adventure	3	It features 10 brand new puzzles, specifically designed to work using the 360 degrees room scale.

[1]Genres of the games are from Steam store [60]

[2]Descriptions of the games are from Steam store[60]

4. IMPLEMENTATION

Due to the changes in the design, the implementation needed also to be flexible. This chapter introduces the survey and its questions, the used motion data capture software and the implementation of the data analyzer software.

4.1. Survey

The survey was used to collect more detailed information about participants' video game playing and exercising habits, as well as their thoughts about exercising by playing VR games. The exact survey questions are in Appendix 1. In Figure 10, a player is playing a BeatSaber game. Figure 10 was taken during previous study by author.

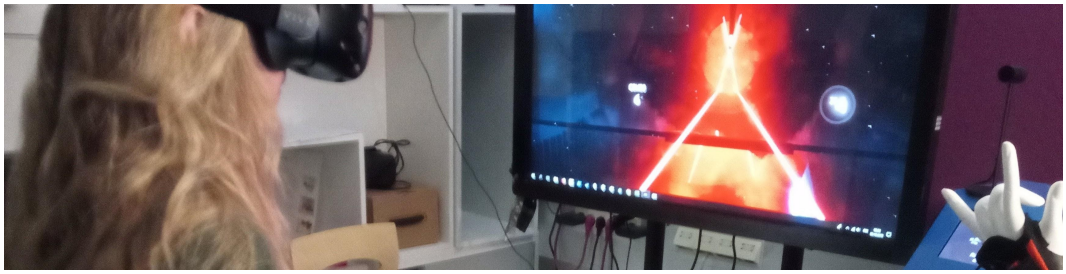

Figure 10. Player plays BeatSaber game. (Figure (c) Author)

At the beginning of the survey, there was a consent letter. The consent letter had eight sections. The first one was a description of the study, then participation, privacy, involvement, risks and benefits, payments, subject's right, and contact information. The full consent letter is in Appendix 1.

On the first page of the survey, the participant was asked to add recorded motion data from the game session. They were advised to play any VR game for at least 15 minutes. A participant was asked what games they were playing.

In the next part of the survey, demographic questions were asked from the participants. The options to choose for gender were female, male, and other, where participants could write their gender. For the age question, the participant could answer only as numbers. For the question of the highest level of education, the participant had the following choices: high school degree or equivalent, bachelor's degree, master's degree, doctorate/Ph.D., or other. The participant's location country could be answered by the name of one's country. The demographic part of the survey continued, and the participant's exercise and gaming habits were asked next.

Participants were asked how much they play video games on a regular week and the options were: less than 15 hours, 15 to 30 hours, and more than 30 hours according to Hussain and Griffiths [71]. By these gaming times, participants can be divided into three gamer types. Those who play less than 15 hours are casual players, those who play between 15 and 30 hours are regular players, and those who play more than 30 hours per week are excessive players [71]. Participants were asked what kind of platforms they use when playing video games and the given options were mobile phone or tablet, computer, home console, or virtual reality set.

The questions about how much the participant does moderate or vigorous-intensity exercise had three options which the participant could choose from: less than 75 minutes, 75 to 150 minutes, and more than 150 minutes. The answer options were from the recommendations of the WHO [72]. The WHO recommends that adults aged 18 to 64 should do at least 150 minutes of moderate-intensity physical activity or at least 75 minutes of vigorous-intensity physical activity during the week [72]. Adults who want additional health benefits should double that amount [72].

The final part of the survey had VR-related questions. Participants were asked whether they would play VR games as for exercise purposes and whether they would recommend that to someone else. The participant gave answers on a Likert-type scale from one to five. One stands for never and five is absolutely. In the previous study where participants were asked these questions, they were more eager to recommend exercising via VR games for others than playing those themselves as a form of an exercise [20].

The next questions were open-ended questions, where participants were asked their thoughts about exercising via VR, and what games they would recommend for exercise purposes. Then participants were asked what motivates them to play VR games. They were asked to answer on a Likert-type scale either 1 (does not motivate me at all), 2 (motivates me a bit), 3 (motivates me), 4 (motivates me quite much), or 5 (motivates me a lot) for following motivation reasons:

- Fun
- Competition
- Exercise
- Social
- Challenge
- Excitement
- Completion
- Escapism

Options *Fun* and *Exercise* were designed for this study. In a previous study, it was discovered that most of the participants would play VR games mainly because they are fun [20]. *Competition*, *Challenge*, *Excitement* and *Completion* were chosen from the research findings of Yee [73]. *Social* and *Escapism* were add from Yee's earlier study from 2006 [74]. Participants had then an option to tell other reasons that motivate them to play VR games.

4.1.1. Google Forms

Survey data was gathered using Google Forms. It was designed to be used for the evaluation plans A and B also, since the data is easy to collect even when participants are interviewed, the survey is easy to spread via a link, and it allows the participant

to upload the motion data. Google Forms survey allowed data to be written by the participants, so no misunderstanding could happen. The final data can be fetched as an Excel form, and it is easy to modify afterward. Google Forms draws diagrams from the answers but in this study, these were not used.

4.2. Implementation

Implementations were required for measuring participants' motion data. The second evaluation plan was to have people with HTC Vive at home to be the participants. To get the motion data from participants they would be provided with a motion data capture program, and to make it useful for them, they would also be provided with an analyzer program. Those programs were supposed to also be a gift for their participation in the study.

4.2.1. Website

For the evaluation plan B, a website was designed and implemented. The website was made because a link is easy to spread over social media and in forums. Two different pages were made, in Finnish and English. Both of the websites included the same contents. The Finnish website can be found from here: `http://www.student.oulu.fi/~ookivela/motioninvr.html`, and the English website from here: `http://www.student.oulu.fi/~ookivela/motioninvr_en.html`. Screenshots of the websites are in Appendix 2. On the upper side of the website, there is the same figure as used in the survey, Figure 10. Then there is a button from the Finnish websites to the English one, and from the English website to the Finnish one. The body text starts with an introduction to the study. Then there are step-by-step instructions. At the beginning of the instructions, there is a link to a downloadable folder. At the end of the instructions, there is a link to the survey. At the end of the website is the author's contact information.

4.2.2. Motion Capture Program

To detect the subject's motions during the game session, a parallel motion capture program was used. The used program is called MotionLogger and it was made by Toni Kuosmanen in 2018 for course project [75]. MotionLogger samples the position and orientation data from the HMD and hand controllers at a rate of 5 Hz. The original code was provided by Valve Software [76] and it was slightly changed to fit in for this research purpose. In the used code printing, the scene was replaced by printing the location.

4.2.3. Motion Data Analyzing Program

A motion data analyzing program was implemented for this study. The analyzer was originally created as a gift for the participants. The participants were supposed to get a program to measure their motion during a game session, and they would also get a program to analyze that data as well. As a result, the analyzer prints two figures. The first one shows one curve for each device (Figure 11). It prints the sum of the total cumulative distance for each device during the game session against the time. The second figure prints the sum of movements from all devices in every time points (Figure 12). It shows the relative distance against time.

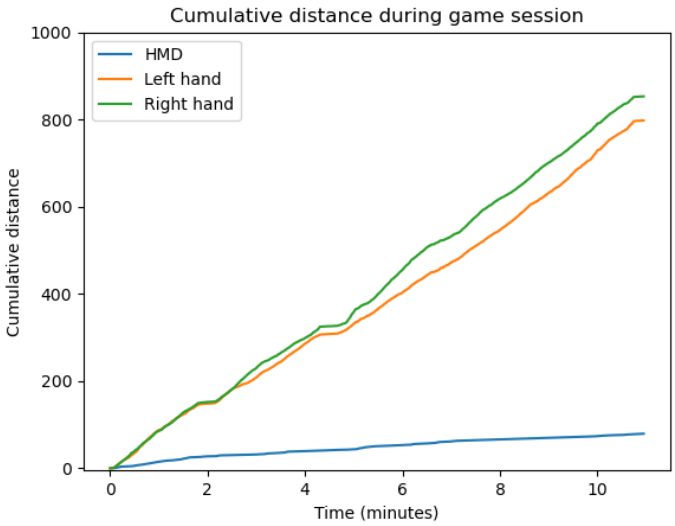

Figure 11. The first figure that DataAnalyzer prints. The blue curve is the sum of the total movements from the HMD, the green curve is the sum of the total movements from the right-hand controller and the orange curve is the sum of the total movements from the left-hand controller against time. In the data of this figure, a player played three songs of Beat Saber.

The data analyzer was created in Python [77] language using version 3.8.1. It first reads the motion data from comma-separated values (CSV). The program goes one row at a time and reads whether the data is from HMD, right or left-hand controllers. It sums the distances from HMD and hand controllers at each time point. It also sums the total distances individually from HMD, left, and right-hand controllers.

The program uses the free Python libraries Matplotlib [78], Datetime, Math, and Scipy [79]. It prints the curves for the user with the Pyplot library in Matplotlib. It reads and modifies time points with the functions of the Datetime library. It uses the Math library's square-root and power.

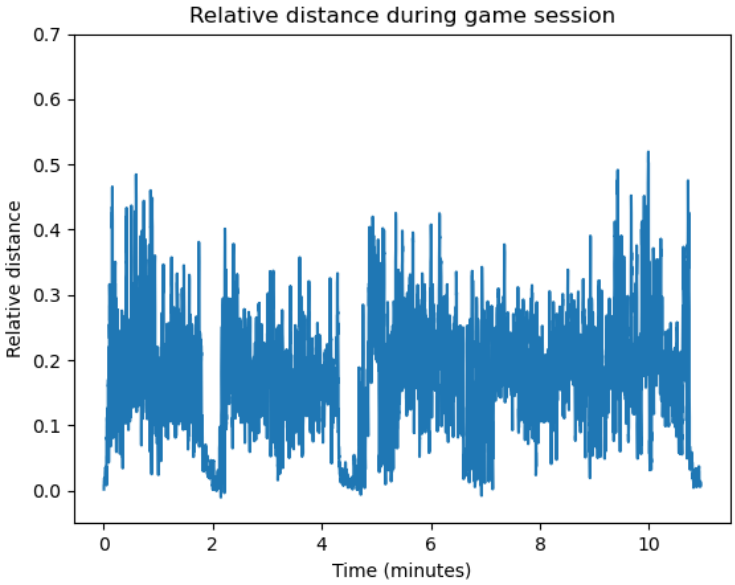

Figure 12. The second figure that DataAnalyzer prints. The blue curve shows the sum of movements from the three devices at each time point. In the data of this figure, a player played three songs of Beat Saber.

5. RESULTS

The results are presented in this chapter. At the beginning of this chapter, the materials and analysis are introduced. An analysis of heart rate data, motion data, survey data, and video analysis data are presented in the following sections. In the Figure 13 is one participant playing *Portal Stories: VR*.

Figure 13. A participant plays *Portal Stories: VR*. (Figure (c) Author)

5.1. Material and Analysis

Heart rate data was measured with a Polar Ignite HRM. It was chosen because it measures the heart rate in each second. The data can easily convert into CSV format, and it can then be modified. The HRM is relatively new, so it should be given accurate heart rate data. The data was successfully captured from eight out of nine participants. It did not capture the data from one participant during one game session. Reasons for

that could be that HRM was not tightened enough, or the participant got sweaty and the bracelet moved a bit.

To be able to compare participants with each other, relative HR was calculated. At first, resting HR was detected from the HR data set. The participants were at the beginning of the session instructed to be seated for five to fifteen minutes. For this research, the used resting HR was the participant's lowest HR point. Because the resting HR is measured before the game session, a participant may have been nervous and excited for the upcoming session, which could have raised the resting state HR.

For the participant's maximum heart rate, a theoretical maximum was used. There are different ways to calculate it when a person's age is known, and in this study, a formula from Robergs and Landwehr was used. [80] The formula is following:

$$HR_{MAX} = 205,8 - 0,685 * age \tag{1}$$

Karvonen introduced the idea of the HR reserve in 1957 [81]. In this study, HR reserve is used to get the relative HR from participants. HR reserve is between resting HR and maximum HR. Maximum HR represents the 100 %, and resting HR 0 %. HR reserve is calculated with the formula:

$$HR_{RESERVE} = HR_{MAX} - HR_{REST} \tag{2}$$

Relative HR data was used to detect changes in the heart rate at each time point. It is calculated with the following formula:

$$HR_{RELATIVE} = \frac{HR_{CURRENT} - HR_{REST}}{HR_{RESERVE}} * 100\% \tag{3}$$

The same formulas have been used in the previous study where two VR games were compared in their fitness level [20].

Motion data was captured with the parallel motion capturing program. It samples the position and orientation data from all the three devices, HMD, left and right-hand controller, at a rate of 5 Hz, and saves it with timestamps into a text file. Data can be used to calculate the relative distance users moved during the game session.

At first, the total amount of movements participant had from all three devices was calculated. This total amount was then divided by the minutes' participant played the game, and multiplied by 15 because the shortest game session between all participant was 15 minutes. The data was then compared between game sessions. The data was relative, and it was compared against the data where the participant had the most movements.

The survey's first part contained demographic questions and participants' video game playing and exercising habits. Four out of nine participants were women and five were men. Participants' ages varied between 26 to 38 years old, the mean age was 30 and the average age was 31 years old. Five out of nine reported that they play video games less than 15 hours per regular week, and all women participants answered this option. A regular week means that the participant was not in quarantine. Three out of nine participants reported playing 15 to 30 hours of video games during a regular week. Home consoles were used the most for video games, and five out of nine

reported using that. The second most reported answer was a mobile phone or tablet and computer. Two participants reported they have VR equipment at home.

Five participants reported that they do moderate-intensity exercises for more than 150 minutes during a regular week, and three of them were women. Three participants do 75 to 150 minutes of moderate-intensity exercise, and only one does less than 75 minutes per regular week. Most of the participants answered that their weekly moderate-intensity exercise consists of household work, walking, and cycling. Two told they also play skittles (kyykkä). Only one participant answered that their work is physical. Three participants do vigorous-intensity exercises for more than 150 minutes during a regular week, and two of those were women. One woman and one man participant do vigorous-intensity exercise 75 to 150 minutes per week, and rest do that type exercises less than 150 minutes. Participants mostly play team sports and ball games, but they also answered that they run and go to the gym.

The next part of the survey had VR related questions. Participants were first asked whether they would play VR games as a form of exercise and then whether they would recommend that to someone else. Answers are shown in Figure 17. The motivation to play VR games was then asked. The answers are shown in Figure 18. Participants had an opportunity to tell other reasons that would motivate them to play VR games. Five participants also reported being motivated because the technology is new and interesting. One was motivated because it is immersive. Participants' thoughts about exercising via VR games were asked. The answers are in Table 2.

Thematic analysis is a method for reporting themes from data. The method organizes the data in detail. Thematic analysis is a qualitative method that is often used in psychology [82]. Thematic analysis is well suited for this study since the participants were observed during their game sessions. In Table 3 are listed the themes found from the analysis. The data was shared also with the supervisor, and it was discussed. We both had similar findings. The final themes were agreed together.

5.2. Heart Rate Data

Individual HR curves at different game's sessions are shown in Figure 14. Figure 14 A. has the HR curve data from game sessions where participants played *Portal Stories: VR*, B. has the HR curve data from game sessions where participants played *The Elder Scrolls V: Skyrim VR*, C. has the HR curve data from the game sessions where participants played *Half-life: Alyx* and D. has the HR curves from the game sessions where participants played *Dance Collider*. Participants played two games each, and participant's HR curves from the different game sessions are shown with the same color. Even for participants that played the same games, HR curves varied quite a bit. Interestingly, those who had more experience in VR had the lowest HR rates (ID 1 and ID 4). Also, those who had played these same games on other platforms had quite low HR curves (ID 5 and ID 8). The highest HR curves were women participants (ID 2, ID 3, ID 6, and ID 7).

Portal Stories: VR game session shows changes in the HR levels for participants with ID's 6 and 9, while the participant with ID 2 HR curve is more stable. *The Elder Scrolls V: Skyrim VR* game sessions show a significantly different HR curve for the participant with ID 7, while others are more stable. The participant's HR curve with

ID 8 shows a slight increase during the game session. Game sessions with *Half-life: Alyx* show that for participants with ID 1, 5, and 8, HR curves did not change much, though the HR curve for the participant with ID 3 shows clear changes. In the game session where participants played *Dance Collider*, participants' HR curves show clear changes. Participant ID 3 had the highest HR curve during the game session. From her data, it can be seen that she played five songs. Participants with ID 1 and 4 had the lowest HR curve. Participants with ID 2, 7, and 9 have similar HR curves.

The average HR curves of all participants for all four games are shown in Figure 15. Even though the individual HR curves varied between participants in the same game session, the averages still show clear differences between games. The average HR curves should not be generalized due to the small number of participants. It can only be used as a directive. There are huge differences in the participants' background with exercising and video gaming, which affect the HR data.

Dance Collider increased participants' HR more than other games. *Portal Stories: VR* increased participants' HR the second most. The average HR curve in *Half-life: Alyx* game sessions is slightly higher than in *The Elder Scrolls V: Skyrim VR*. *Dance Collider* and *Portal Stories: VR* average HR curves show a slight increase in the data during time compared to starting the game session, while *Half-life: Alyx* and *The Elder Scroll V: Skyrim VR* HR curves stay in the same level.

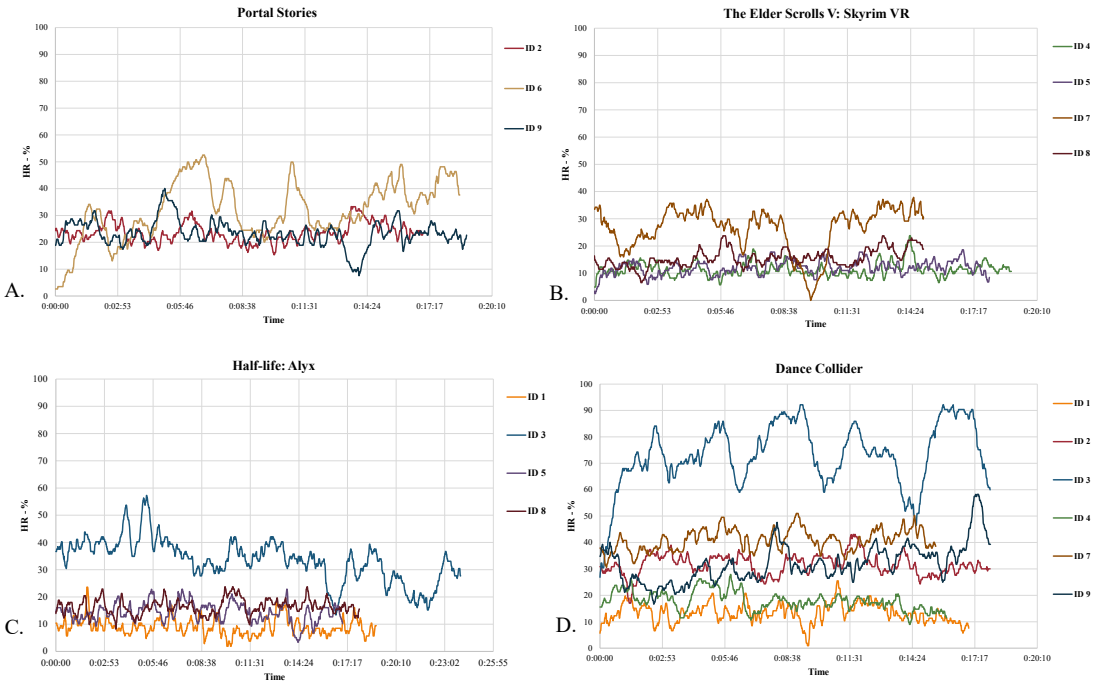

Figure 14. Relative HR data from each game session. Time on X-axis and relative HR on Y-axis. **A.** HR curves from three participants who were playing *Portal Stories: VR*. The red curve represents the HR data from the participant with ID 2, the light-brown curve is from the participant with ID 6 and the dark-blue curve is from the participant with ID 9. **B.** HR curves from four participants who were playing *The Elder Scrolls V: Skyrim VR*. The light-green curve represents the HR data from the participant with ID 4, the purple curve is from the participant with ID 5, the brown curve is from the participant with ID 7 and the dark-red curve is from the participant with ID 8. **C.** HR curves from four participants who were playing *Half-life: Alyx*. The yellow HR curve is from the participant with ID 1, the blue curve is from the participant with ID 3, the purple curve is from the participant with ID 5 and the dark-red curve is from the participant with ID 8. **D.** HR curves from six participants who were playing *Dance Collider*. The yellow HR curve represents the data from the participant with ID 1, the red curve is from the participant with ID 2, the blue curve is from the participant with ID 3, the light-green curve is from the participant with ID 4, the brown curve is from the participant with ID 7 and the dark-blue curve is from the participant with ID 9.

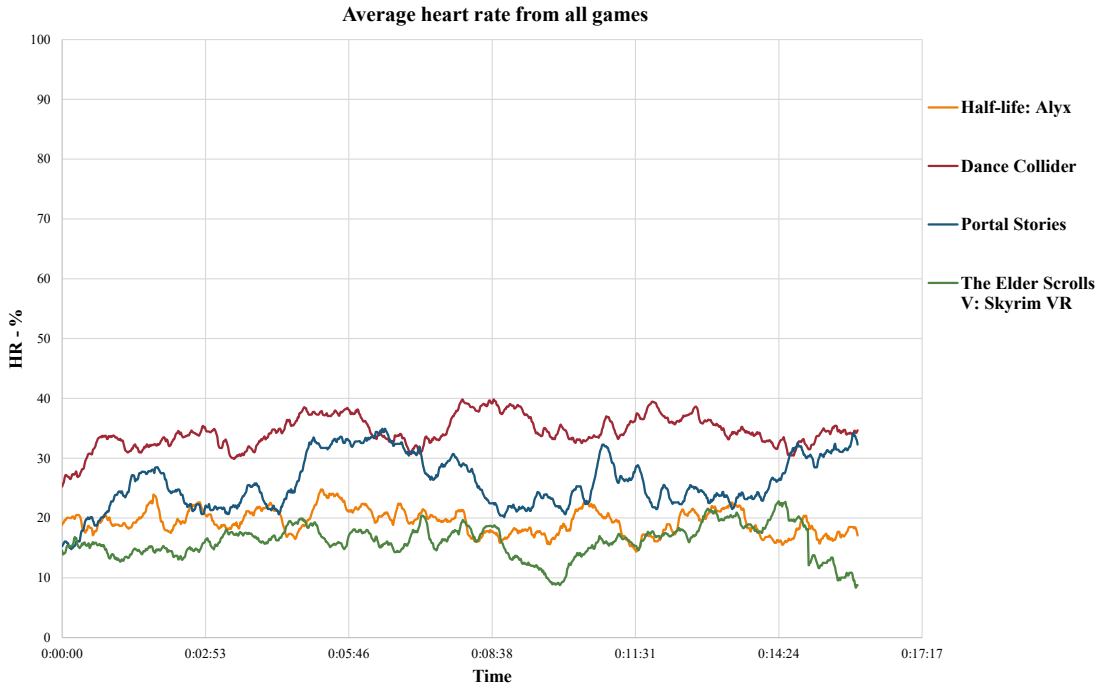

Figure 15. Average relative heart rates of all the participants at each of the different game sessions. The yellow curve represents the average HR data from all participants from the *Half-life: Alyx* game session, the red curve represents the average HR data from all participants from the *Dance Collider* game session, the blue curve represents participants average HR data from the *Portal Stories: VR* game session, and the green curve is participants' average HR data from the *The Elder Scrolls V: Skyrim VR* game session.

5.3. Motion Data

Relative distance from each game session is shown in Figure 16. Motion data is the sum of motions from all three devices, which is then compared to the sum of the data of the participant who moved the most during one game session. Each participant played two games.

Dance Collider moved the participants most. Participants had the second most movements in the *Portal Stories: VR* game session, and third-most in the *Half-life: Alyx* session. Participants had the least movements when playing *The Elder Scrolls V: Skyrim VR*. Participants who played both *Half-life: Alyx* and *The Elder Scrolls V: Skyrim VR* had fewer movements when playing the latter. All participants who played *Dance Collider* had more movements during that game session compared to the other game session they played. Due to the small number of participants, the data should not be generalized.

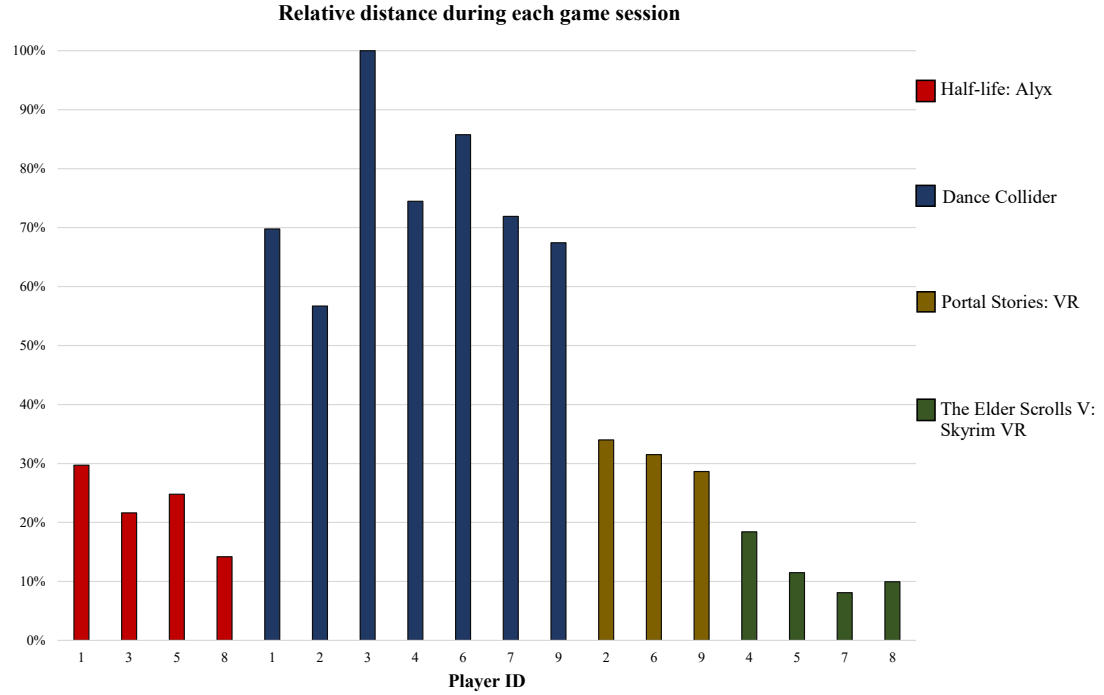

Figure 16. Relative distance during each game session. Participant ID is shown on the X-axis, the relative distance is shown on the Y-axis. Red bars are from the game sessions where participants played *Half-life: Alyx*. Blue bars are from the game session where participants played *Dance Collider*. Gold bars are from the game session where participants played *Portal Stories: VR*. Green bars are from the game session where participants played *The Elder Scrolls V: Skyrim VR*.

5.4. Survey Data

In Figure 17 are collected answers from survey to two questions: "Would you play VR games as a form of an exercise?" and "Would you recommend VR game playing as an exercise form to someone else?". Answers were given in scale 1 "Never" to 5 "Absolutely". Four answered 5, three answered 4, one answered 3 and one answered 2, they would recommend VR games for an exercise to someone else. Two answered 5, five answered 4, two answered 2, that they would play themselves VR games as an exercise form.

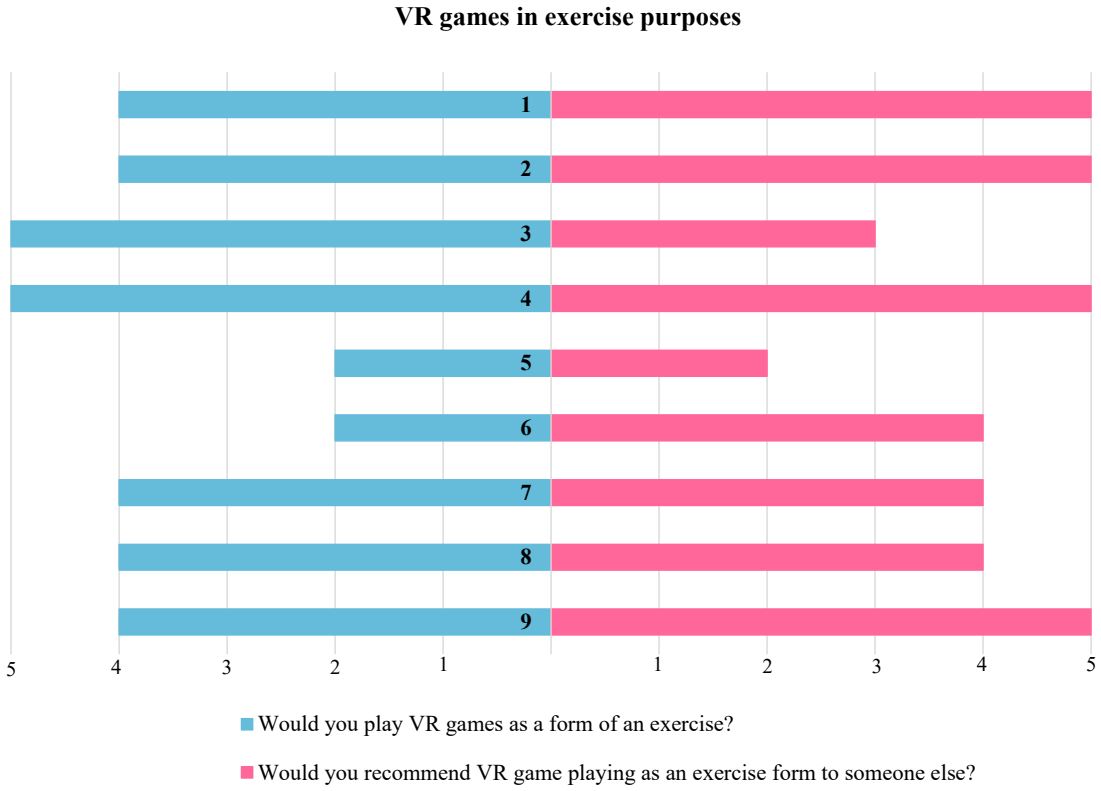

Figure 17. Participants' answers from the survey. Questions were "Would you play VR games as a form of an exercise?" and "Would you recommend VR game playing as an exercise form to someone else?" In the middle of the figure is shown participants ID number. Blue bars represent participant's answer for the question whether they would play VR games as an exercise form, and pink bars represent participant's answer if they would recommend VR game playing as an exercise form to someone else. Answer scale was from 1 "Never" to 5 "Absolutely".

Figure 18 represents participants' answers to the reason what would motivate them to play VR games. Eight different motivation factors which participant rated between "Does not motivate me at all" to "Motivates me a lot". The data is Likert-type, and percents were calculated for each motivation reason. "Fun" was the main motivation for playing VR games among the participants. "Excitement" and "Completion" were the next motivation reasons for playing VR games, following "Competition" and "Challenging". "Socializing" was the only motivation reason which got also the answer "Does not motivate me at all". "Exercising" did not motivate most of the participants much. From the eight motivation reasons "Escapism" motivated participants least.

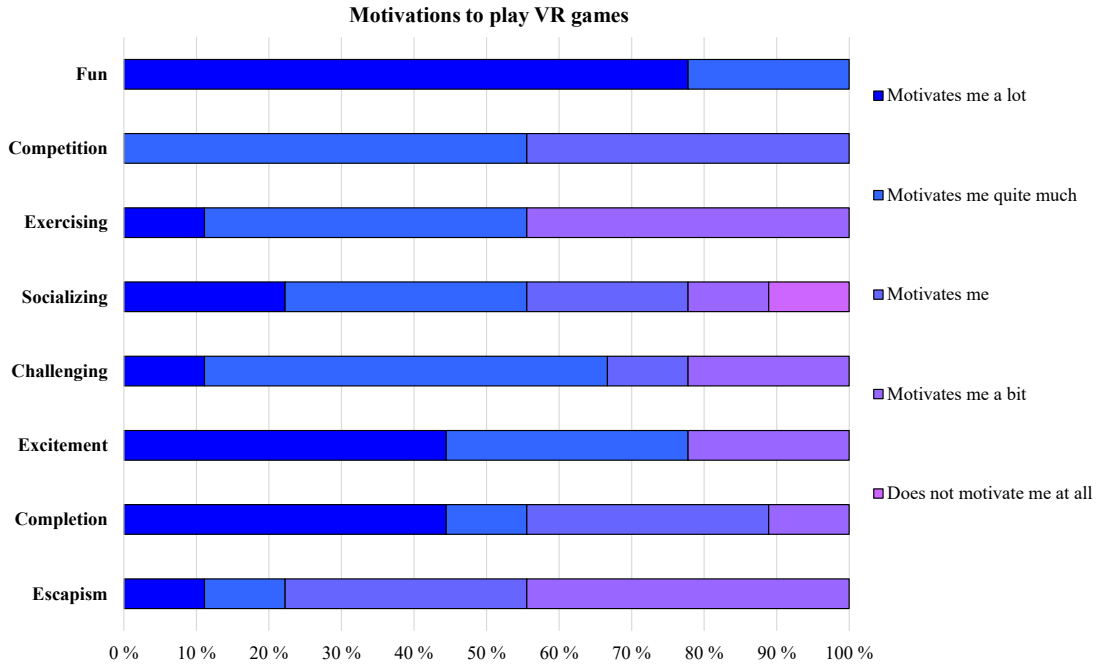

Figure 18. Participants' answers from the survey. Participants rated how much eight different reasons motivate them to play VR games. Total percentages of all participants are shown. Motivational reasons are on the left side of the figure from up to down; "Fun", "Competition", "Exercising", "Socializing", "Challenging", "Excitement", "Completion" and "Escapism". The dark blue bar represents "Motivates me a lot", lighter blue bar represents "Motivates me quite much", light purple bar represents "Motivates me", purple bar represents "Motivates me a bit" and pink bar represents "Does not motivate me at all". 100 % represents all answers.

Participants thoughts about VR games as an exercise form are shown in Table 2.

Table 2. Participants' answers to the question "What are your thoughts about exercising by playing VR games?" Participants with ID 2, 4, 6, 7, 8 and 9 answers are translated by the author from Finnish to English.

ID	What are your thoughts about exercising by playing VR games?
1	VR games are a great way to spend time, have a good time and it's a good way to get "accidental" workout when games are intensive enough.
2	Good option for moderate-intensity exercise, especially on the rainy days.
3	It's fun. I'd still rather do sports together with teammates, but if that is not possible, then VR is a good option to do exercise by myself.
4	Sounds like something I would try.
5	Most movement is only done by moving hands. Alas, it is not a very active form of exercise.
6	Seems pretty good exercise along with other sports. I favor as diverse as possible exercise so I would not leave the exercise depending only on VR games.
7	Fun and easy. It could be used as a break workout.
8	Activity which slightly increase the heart rate.
9	For some people, it would be very suitable. For example to the persons who do not like to exercise, but who like to play videogames.

5.5. Thematic Analysis

Thematic analysis revealed seven themes from the data of video recording and notes of game sessions. These themes are listed in Table 3. The listing includes the theme, the number of cases in which the theme was detected, and a short description of the theme. Each theme was detected from three to nine participants' game sessions.

Table 3. Themes, how many participant was affected to theme and theme descriptions found from the data.

Theme	**Women**	**Men**	**Description**
Enjoyment	4	5	The feeling participant got during the game session.
Activity-inducing	3	1	Technology induced the activity of participants during the game sessions.
Motion sickness	3	1	Motion sickness symptoms made participants feel uncomfortable.
Excitement	4	0	Participants were scared of heights and creatures of the game, but at the same time it made the game fun.
Novelty effect	2	1	The technology itself was new and interesting.
Self competence	3	0	Competence to play the games was not high.
Conflict between digital and physical worlds	2	2	Conflicts between physical and virtual worlds appeared during game sessions.

One clear theme observed in game sessions was *Enjoyment*. It was discovered in all participants game sessions. It was not only detected from participants' comments, but participants also laughed and smiled while playing. For one participant, there were a lot of technology difficulties, but at the end of game session he thought that it was still quite fun. Below are listed some of their expressions from the game sessions. Quotations are translated by the author.

- "The latter game was fun!"
- "Jeez, this is fun!"
- "Ah, cool, I can hit!"
- "Yep, this mage system is funny"

- "This is quite fun"

Activity-inducing was also pointed out from the game sessions. It was detected in the comments of four participants. All cases of this theme were founded in the *Dance Collider* game sessions. It was found in three women participant sessions and in one male participant session. Below are the comments from them. Comments are translated by the author.

- "I got sweaty already"
- "By the way, this is pretty effective"
- "It got me sweaty"
- "This will, like, totally raise the heart beat"
- "During this, I should've be wearing a T-shirt"

Four participants had slight symptoms of *Motion sickness*. It is the next theme found in the data of the video recording. It was detected in the comments of the participants. *Motion sickness* arose during locomotion, either teleporting or walking in the game. It was shown in *Half-life: Alyx*, *Portal Stories: VR* and *The Elder Scrolls V: Skyrim VR* game sessions. Below is a list of comments, which are translated by the author.

- "Can I sit down?"
- "Ugh! This is nasty! That teleporting was nicer way to move"
- "I'm starting to feel dizzy, but I'll continue"
- "Jeez, I got a little unwell"

The next identified theme is *Excitement*. It was observed from four participants. Participants were scared of heights or creatures in the game, but in a good way. They laughed after they got a little frightened. This was detected only from women participants. Especially game sessions with *Portal Stories: VR* evoked excitement, because participants were a little scared when they were in high places. Also, *Half-life: Alyx* and *The Elder Scrolls V: Skyrim VR* evoked the excitement due to the scary creatures in the game. The intensity of *Dance Collider* also evoked excitement because the cubes were coming towards the player fast. Below are citations from the game session, which are translated by the author

- "Ugh, horrible! Ugh!"
- "Eek, I am so high!"
- "Ugh, I am just here at the edge! I can't stand this close to the edge!"
- "I hope there isn't anybody?! What place!? Oh no!"
- "What is that!? I died!! That is something awful, I died. It lifts me up, I am in its mouth. Hm."

- "Eek, it is so nasty here at the edge!"
- "Eek, what is that?!"
- "Is that a spider?! It probably attacks!"
- "There is someone up there! Where is my buddy?"
- "Help, I am not prepared for a fight!"
- "What is there?! I am getting a little afraid!"
- "Help! Wait me old man!"
- "Ugh damn! It was just my friend."
- "Help! Where those come from!? Help!"

A theme called *Novelty effect* was observed from the notes from the test sessions. Three participants, two women and one man, thought that the technology itself was new and interesting. After trying the games, participants expressed that by saying that they would like to buy the VR equipment at home. One participant said that she would use it at home for exercising. It is good to keep in mind that two participants already have a VR setup at home. Below is one comment from a participant, which is translated by the author.

- "It might be that we need to buy one of those"

Another theme found from the video recordings and notes from the game sessions is *Self competence*. Three participants felt that they were not good at the game they were playing. The games that evoked those feelings were *Half-life: Alyx*, *Portal Stories: VR* and *The Elder Scrolls V: Skyrim VR*. All of these participants were women. Even they felt that way, they still had a good time and they were laughing during the game session. One of these participants said already before game session that she won't be very good at these games. Below are comments from the game session, translated by the author.

- "This could otherwise take quite some time"
- "This is quite impossible for me"
- "I can't go there. I am a little bad at this."

The last detected theme was *Conflict between digital and physical world*. It was observed from four participants. One really tall male participant accidentally touched the ceiling a couple of times during the game sessions but he did not mind that. Another male participant hit the couch a few times during the game session. He thought it was irritating. He also was irritated that the television was behind him, and the sound came from somewhere in the back. The couch was too close when playing *Portal Stories: VR* where player needs to squat to avoid to get to shot. One female participant hit the TV but it did not bother her. Another female participant was concerned about her position in the room. Below are a couple of comments from participants, translated by the author.

- "It’s funny when you spun there and have no idea which way are you facing in the room."
- "How fun, that this was also there under feet. Haha!"
- "I wouldn’t dare to play this alone. How scary when you can’t see your surroundings."

6. DISCUSSION

This research explores the physical and motivational aspects of VR games from different genres. The discussion is structured based on the research questions. Following that are the other observations and limitations. At the end of this chapter, potential future work is presented.

6.1. RQ1: How Do Different Genres of VR Games Vary in the Sense of Perceived and Observed Exercise Intensity and Self-Reported Motivation?

To answer RQ1, HR and motion data were collected from participants. Heart rates increased the most when participants played *Dance Collider* (Figure 15). *Dance Collider*, as the name predicts, is a dancing game, and to accomplish higher scores participants need to make a physical effort. The longest distance was moved when participants were playing *Dance Collider* (Figure 16). It is not surprising since the HR data showed the same trend (Figure 15); the game is very physical. Thematic analysis reveals the same outcome as one of the discovered themes, *Activity-inducing*, was observed only from *Dance Collider* game sessions (Table 3). It was detected from four participants, and they said that they got sweaty and their HR increased.

Half-Life: Alyx and *The Elder Scrolls V: Skyrim VR* are both open-world action games (Table 1), and participants' HR did not rise during the game sessions (Figure 14 B. and C.). Participants started their *The Elder Scrolls V: Skyrim VR* and *Half-life: Alyx* game sessions after an introduction, and the game had a lot of storytelling when participant stood still. When participants were playing *The Elder Scrolls V: Skyrim VR* they moved the least, and in *Half-life: Alyx* they moved the second least. These same trends can be seen also from the HR data (Figure 15). A theme *Excitement* was observed from the video recordings when participants were playing these both games (Table 3). Participants were scared of the creatures in the game. One participant (ID 7) even screamed during the *The Elder Scrolls V: Skyrim* game session but laughed right after. Even after the scream, her HR did not show any specific peak (Figure 14 B.). Also a theme *Self competence* was discovered from the video recordings from the *Half-life: Alyx* and *The Elder Scrolls V: Skyrim VR* game sessions. Participants said during the game session that they are not very good at the game. Low *Self competence* was only detected from game sessions of women participants. One reason is that both games are hard to learn, and fifteen minutes is a very short time to learn the buttons. Additionally, VR technology was new to these participants. Most of the participants were not familiar with the locomotion, and they had slight symptoms of *Motion sickness* while they played *Half-life: Alyx* and *The Elder Scrolls V: Skyrim VR*. *Motion sickness* is one of the themes found in the video recordings (Table 3).

Portal Stories: VR game sessions raised participants' HR the second most (Figure 15). Especially during the *Portal Stories: VR* game session, instead of pressing the button participants turned more around and took steps forward, and they actual crouched when needed, while in the *Half-life: Alyx* and *The Elder Scrolls V: Skyrim VR* game sessions participants used more the buttons of the controllers. One reason for this might be that the locomotion in the game was new to most of the participants. *Portal Stories: VR* made participants to move the second most (Figure 16). Thematic

analysis (Table 3) revealed that *Motion sickness* occurred also in the *Portal Stories: VR* game session, where participants teleported. Participants were scared of heights and the *Excitement* theme was found from the video recordings in the *Portal Stories: VR* game session. One participant thought that she was not good at the game, so also a *Self competence* theme found from the *Portal Stories: VR* game session.

For participants who have played VR games more and who have the equipment at home, HR did not rise as much as for other participants. For example, in the Figure 14 D. the two lowest HR curves (ID 1 and ID 4) in *Dance Collider* game sessions are from these participants. Their HR curves are the lowest ones also in the game sessions *The Elder Scrolls V: Skyrim VR* Figure 14 B. (ID 4) and *Half-life: Alyx* Figure 14 C. (ID 1). They are used to playing VR games and are familiar with how the buttons work, so they did not need to try to reach out to anything or to step closer if they wanted to go somewhere. But even though their HR stayed low, the motion data was at the same level as others or even slightly higher (Figure 16). The reasons for this might be that because they are used to VR, the game session itself was not as exciting as for others, raising other participants' HR. In Figure 16, the participant with ID 1 moved the most while playing *Half-life: Alyx* and the participant with ID 4 moved the most while playing *The Elder Scrolls V: Skyrim VR*. The motion differences are small, and when they played the *Dance Collider* their motion data was neither high nor low. Only one theme was found from these two participants, and it was *Enjoyment*.

Participants with IDs 5, 8 and 9 play console and computer games a lot. The data for participants with ID 5 and ID 8 HR is not as low as those participants who have VR equipment at home, but their HR is also clearly lower in *The Elder Scrolls V: Skyrim VR* and *Half-life: Alyx* game sessions (Figure 14 B. and C.). The highest HR curves are from women participants', whose IDs are 2, 3, 6 and 7, in all four game sessions (Figure 14 A., B., C., and D.). Survey answers reveal that women participants are also slightly more physically active. The participant with ID 3 is an athlete, and that can be seen in her HR data in *Half-life: Alyx* and *Dance Collider* game sessions (Figure 14 C. and D.). Her HR increased most during the game sessions.

Thematic analysis showed that all of the participants enjoyed the game session and the theme *Enjoyment* was detected from every participant (Table 3). They laughed and smiled during the game sessions. Participants also rated "Fun" as the highest from the eight reasons that motivate them to play VR games (Figure 18). The other seven motivation reasons from highest to lowest are "Excitement", "Completion", "Competition", "Challenging", "Socializing", "Exercising" and "Escapism". In the scope of this study, "Exercising" is an especially interesting motivation reason. Participants thought that "Exercising" would motivate them to play VR games less than, for example, "Challenging". This, on the other hand, explains why participants would rather recommend VR games as an exercise for others than play themselves for that reason(Figure 17). "Excitement" was rated as the second highest motivation reason, and the theme *Excitement* was also discovered from the thematic analysis. This means that the games participants were playing motivated them from an "Excitement" point of view. "Escapism" was rated lowest from the eight motivation reasons, and while participants answered the survey some of them asked what that means. The fact that participants just learned the meaning of the word might also have affected the result. Other motivation reasons participants answered were "Immersion" and

"Novelty". Four participants answered “Novelty”. From the thematic analysis, *Novelty effect* was also found as one of the themes.

Dance Collider made the participants move the most, and it increased their HR, which the participants themselves also noticed. The *Portal Stories: VR* game sessions moved the participants and raised their HR the second most, but participants did not notice that. The HR increase in *Portal Stories: VR* was comparatively low, and it can not be considered as an exergame.

6.2. RQ2: How Likely Are Users to Play VR Games as a Form of Exercise?

Survey data was used to answer the RQ2. Participants were asked whether they would play VR games as an exercise form and whether they would recommend it to someone else. Participants were slightly more eager to recommend it than to play it themselves. The answers to these questions from the survey are shown in Figure 17. Only one participant had rated the option to play VR games by oneself higher than to recommend it to others. Participants with ID 4, 5, 7, and 8 were as likely to play themselves as to recommend to someone else. The rest of the participants would rather recommend it to others than play it themselves. Reasons for this can be found in Table 2, which shows participants’ thoughts about exercising by playing VR games. Women participants reported that they could add VR exergames as a part of their normal exercise routines, which indicates that they feel like they would not necessarily need more exercise. One of the men participants thought that VR exergames could be a great way to exercise for some people who do not exercise in other ways but who like to play video games. Maybe some of the other participants thought similarly. As discussed in the previous paragraph, participants rated the motivation reason "Exercise" as the second-lowest of the eight reasons. This indicates that exercising is not one of the main reasons to play VR games for participants.

6.3. RQ3: What Conflicts Are There between Physical and Virtual Environments, and How Do They Influence the Player Experience in VR Games?

As an answer for RQ3, a thematic analysis (Table 3) revealed that participants had *Conflicts between digital and physical worlds*. Two participants did not mind that they touched something like the ceiling or television during game sessions, but one was annoyed that he collided with the couch and he was standing with his back towards the television where the sounds were coming from. One participant was aware of the surroundings and thought that it was scary that she can not see her surroundings while playing. She would not dare to use the VR equipment alone either. The observed conflicts did not have a huge impact on the participants’ experience. If the game sessions would have lasted longer, the conflicts could have had a bigger role in participant experience. For example, the couch could have started to irritate the participant more if he continued the game session for another fifteen minutes.

6.4. Other Observations

Even though participants' fitness levels vary quite a bit, relative HR enables the data to be compared between participants. Maximum HR was calculated with the formula which uses participant age as one measure. This may cause participant maximum HR to be higher or lower than it really is, but yet it is a widely used formula. Participants' resting HR was measured while they were seated before the game sessions. Even though the situation was relaxed, they may have been nervous or excited about the upcoming game sessions. The effect of the participant's height to motion data is not taken into account.

Differences in the habits of genders are interesting. This study with a small number of participants showed some differences. Two of the discovered themes were only observed in women participants' game sessions. These themes were *Excitement* and *Self competence*. Also, participants' background with video games could affect this observation. Men participants played more video games than women, while women were more physically active. This result is not surprising, since men are twice likely to describe themselves as active players than women [50]. The experience of playing any video games may affect self-competence. Also, the threshold to reveal one's self-competence may be higher in men due to the pressures from society. Only women participants answered when their thoughts about exercising via VR were asked that exercising via VR could be done in parallel with other exercises (Table 2). Male participants' answers were from a different point of view. They thought the exercising via VR would be a good option for others or they would try it themselves. They also thought that it probably is not that effective since one can just move only their hands. The gender difference in thoughts is very interesting. One explanation could be that since women participants are physically more active, they project the answer for their lives. All data gathered during this study are directive due to the low amount of participants, and it should not be generalized.

6.5. Limitations

One of the biggest limitations of this study was the COVID-19 pandemic. It was unfortunate that the restrictions started just before the evaluation was supposed to start. It forced the evaluation plan to be changed not once, but twice. The final study in this way has a more qualitative point of view.

During the test sessions, there were quite a few technical problems. Even though the game area was re-synchronized many times, the participants still faced issues where the base stations lost track of one hand controller or the whole player. With one participant, even after the synchronization the game placed him high above the ground. As most of the participants were experiencing VR for the first time, it was unfortunate that these issues arose. The hardware used has been on the market for a while and it has been well tested before it started to be sold. A lot of users ran into these same problems from time to time. The specific HTC Vive used in this study was not brand new. These technical problems were not critical, and all the game sessions were successful and enjoyable for participants. Two participants thought that the other game they played was boring.

These games were *Dance Collider* and *Portal Stories: VR*. They still enjoyed the game sessions.

Because of the pandemic restrictions, participants in this study were author's close friends. The sample is somehow biased and this effect on the findings should be taken into account. All of the participants live in Oulu, Finland. Eight out of nine participants have higher education. Participants share somewhat similar values since they are the author's close friends. Pandemic restrictions also limited the amount of participants. To complement the smaller sample size, richer qualitative data was collected, and the game sessions were video recorded. For safety reasons, only people author had seen during the restrictions were asked to participate. It is unusual to use close friends for studies, but in this case, participants were more relaxed around author which made observation awkwardness easier. Participants were also more comfortable to ask questions if they had some during the study.

The restrictions of the pandemic also forced the test setup to be placed at author's home. This should be taken into account in the results of the conflicts between physical and virtual worlds. To avoid these conflicts the size of the game area should have been wider.

6.6. Future Work

It would be interesting to develop motion capture and data analyzer programs that are more user friendly and see whether players would use them. These two could be combined so that they could be used by pressing one button and the outcome could be dynamically modified. These days a mobile app would be used for this. That type of motion capture and analysis program could have the potential to break through into the market.

This study could be continued by increasing the number of participants and games. A wider variety of game genres could be used. With a larger participant group, potential differences between genders might be clearer. Even with this study consisting only of four women and five men participants, the data revealed gender differences. How clear or unclear these gender differences would be if the number of participants would be multiplied remains to be seen. It was also interesting that most of the participants would rather recommend VR games as a form of exercise for others than play VR games as exercise for themselves. The motivational reasons for this would be interested to study as well.

7. SUMMARY

This thesis explored the potential of exercising by playing VR games from three different points of view. First, this thesis answers how do the different genres of VR games vary in the sense of perceived and observed exercise intensity and self-reported motivation. Second, participants' willingness to play and recommend VR games as a form of exercise. Third, participants' conflicts between the physical and virtual worlds and how these conflicts influence the player experience while playing VR games are observed and analyzed.

This study had nine participants. The COVID-19 pandemic and the restrictions it caused were the reason that the number of participants was comparative low. This on the other hand made a room for more qualitative analysis of the results. Informed consent was asked before the participation. Each participant played two VR games of their choice. Played games were *Half-life: Alyx*, *The Elder Scrolls V: Skyrim VR*, *Portal Stories VR* and *Dance Collider*. Participant's HR was measured from wrist with Polar Ignite HRM. Motion capture program collected the positions of HMD and the controllers during the game sessions. Game sessions were video recorded and observed. After two game sessions, a participant answered the survey.

This study revealed that *Dance Collider* game session moved the participants most. Participants HR increased more in *Dance Collider* game session than in the other games. Based on the thematic analysis, a theme *Activity-inducing* was observed from *Dance Collider* game sessions, which advocate the biometrics results. Four participants expressed that they felt sweaty or their HR increased during *Dance Collider* game sessions. *Portal Stories VR* game sessions increased the HR second most, and participants had the second most movements as well. The third most participants moved and their HR increased while playing *Half-life: Alyx*. The lowest HR curves and the least motions were made when participants played *The Elder Scrolls V: Skyrim VR*.

Theme *Enjoyment* was found from all participants' video recordings of game sessions. The answers from survey reveal that participants ranked "Fun" as the highest of the eight reasons which motivate them to play VR games. The motivation reason "Exercise" on the other hand was ranked the second lowest. Participants were asked to add some other reasons that motivate them and four participants answered: the novelty of the technology. *Novelty effect* was also one theme found by thematic analysis.

Survey answers show that most of the participants would rather recommend exercising via VR games than exercise themselves. Women thought that they could add it to their daily exercise routines but would not think that it should cover all daily exercises. Only one participant would rather exercise herself by playing VR games than recommend that to others.

Four participants had a conflict with the physical world during the game session. Three of those touched furniture of the room, only one of those thought that it was irritating that the couch was too close. One participant felt that it is scary to wear the HMD since one can not see the physical surroundings. She said that she would not dare to play VR games alone because of the above reason.

As other observations, a thematic analysis from the data exposed gender differences from the game sessions. Women's HR increased more than men's during game sessions. The difference in the fitness levels of participants affects the HR data.

Themes *Excitement* and (low) *Self competence* were observed from only women participants. "Excitement" was ranked second highest out of eight motivational reasons to play VR games. Participants had a different background which has a great influence on the results. Men play more video games and women exercise more.

This study aimed to find answers for three research questions related to exercising via VR. All of the questions were answered. During this study gender differences were observed but those are directive and should not be generalized. There is a place for more detailed research with a larger number of participants.

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9. APPENDICES

SURVEY

CONSENT LETTER:

- DESCRIPTION: This survey gathers information for the motivational aspects of exercising via virtual reality technology. The survey is run by Center for Ubiquitous Computing, University of Oulu, Finland. This research study consists of three sections: 1) uploading motion data, 2) demographic and background questions, and 3) questions related to VR games.
- PARTICIPATION: You may discontinue your participation at any time without penalty.
- PRIVACY: The information that you will provide will be used only for scientific purposes. Individual responses are pseudonymised and individuals cannot be recognized from reports or publications created based on the collected data. This research is conducted in accordance to the Finnish National Board on Research Integrity's guidelines for research integrity and ethics.
- INVOLVEMENT: Your participation in this study will take between 5-10 minutes.
- RISKS AND BENEFITS: This study poses no physical risks beyond those involved in normal, daily reading, writing, and computer tasks. There are no foreseeable social, or legal risks.
- PAYMENTS: You get motion capture program and also a data analyzer program to analyze the motion data for your later use.
- SUBJECT'S RIGHTS: If you have read this form and have decided to participate in this project, please understand your participation is voluntary and you have the right to withdraw your consent or discontinue participation at any time. You have the right to refuse to answer particular questions.
- CONTACT INFORMATION: If you have any questions, concerns or complaints about this research study, its procedures, risks and benefits, you may contact Oona Kivelä, oona.kivela@student.oulu.fi

PART 1

- Please upload your motion data here (vroutput.csv)
- What VR game were you playing when recording the uploaded motion data?

PART 2

- What is your gender?
  - Male
  - Female
  - Other

- How old are you?
- What is your highest level of education?
  - High school degree or equivalent
  - Bachelor degree
  - Master's degree
  - Doctorate / PhD
  - Other
- Where are you located (country)?
- How much do you play video games in a regular week? Regular week means that you are not in a quarantine.
  - Less than 15 hours
  - 15 to 30 hours
  - More than 30 hours
- What kind of platform(s) do you use for playing video games?
  - Mobile phone or tablet
  - Computer
  - Home console
  - Virtual reality set
- How much do you do moderate intensity exercise in a regular week? Moderate intensity means that you can easily speak while exercising e.g. walking, and regular week means that you are not in a quarantine.
  - Less than 75 minutes
  - 75 to 150 minutes
  - More than 150 minutes
- What type of moderate intensity exercises you do?
  - Walking or running
  - Cycling
  - Household
  - My job is physical (eg. nurse)
  - None
- How much do you do vigorous intensity exercise in a regular week? Vigorous intensity means you get breathless and sweaty e.g. playing football, and regular week means that you are not in a quarantine

  - Less than 75 minutes
  - 75 to 150 minutes
  - More than 150 minutes

- What type of vigorous intensity exercises you do?
  - Running
  - Spinning
  - Dance
  - Gym
  - Team sports and ball games
  - Acrobatics
  - None

PART 3

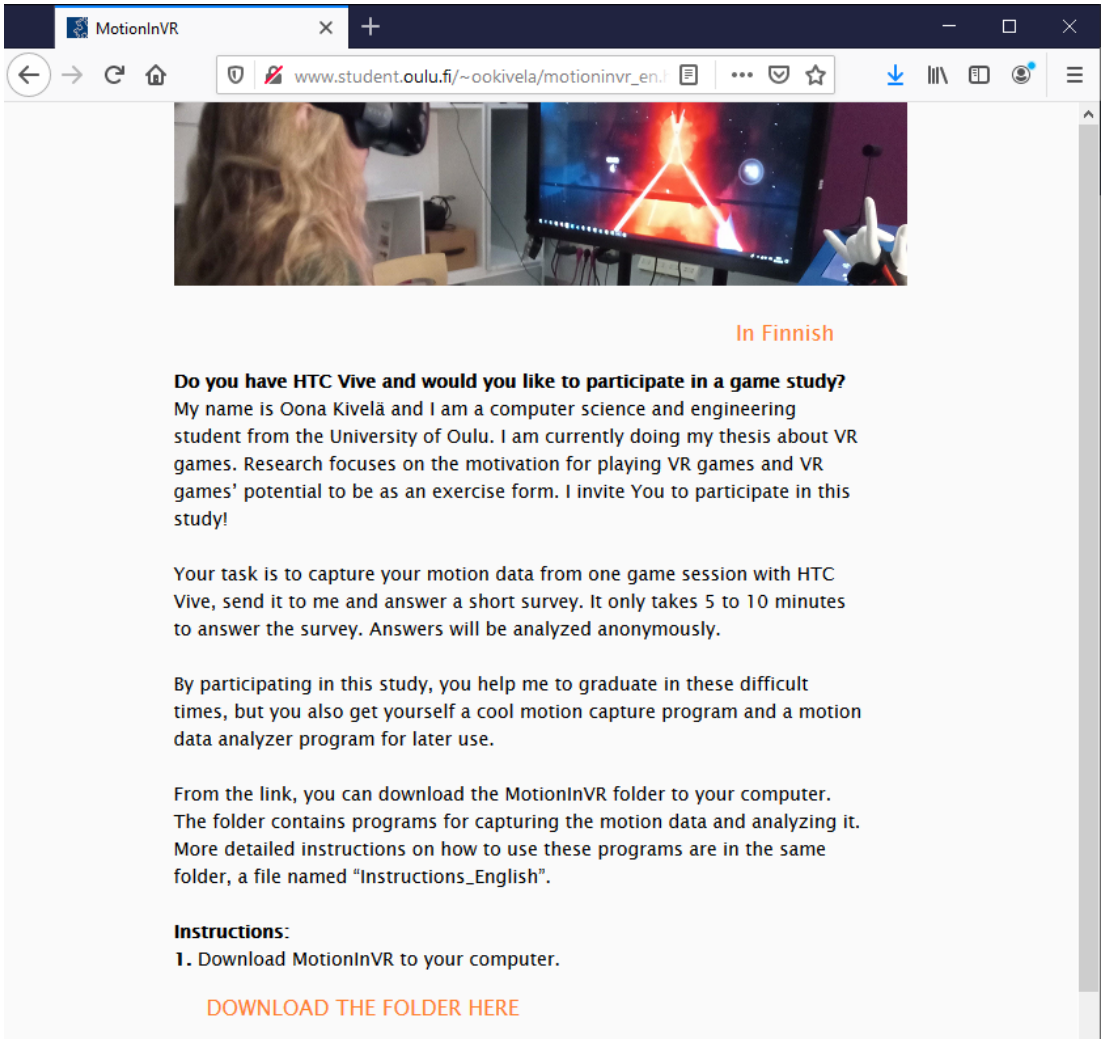
- Would you play VR games as a form of an exercise?
  - 1 Never
  - 2
  - 3
  - 4
  - 5 Absolutely
- Would you recommend VR game playing as an exercise form to someone else?
  - 1 Never
  - 2
  - 3
  - 4
  - 5 Absolutely
- What are your thoughts about exercising by playing VR games?
- What existing VR games would you recommend to be used for exercise purposes? You may name many.
- In scale 1 to 5 please determine your motivations to play VR games
  - Fun
    - 1. Does not motivate me at all
    - 2. Motivates me a bit
    - 3. Motivates me
    - 4. Motivates me quite much

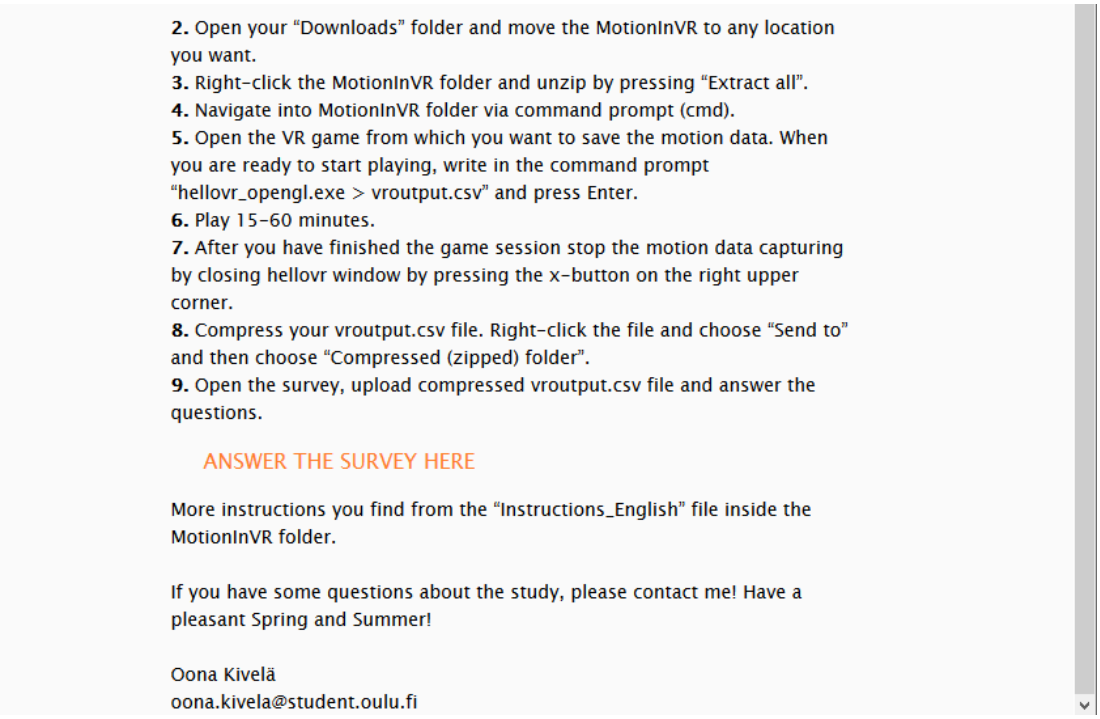
    - 5. Motivates me a lot
- Competition
    - 1. Does not motivate me at all
    - 2. Motivates me a bit
    - 3. Motivates me
    - 4. Motivates me quite much
    - 5. Motivates me a lot
- Exercise
    - 1. Does not motivate me at all
    - 2. Motivates me a bit
    - 3. Motivates me
    - 4. Motivates me quite much
    - 5. Motivates me a lot
- Social
    - 1. Does not motivate me at all
    - 2. Motivates me a bit
    - 3. Motivates me
    - 4. Motivates me quite much
    - 5. Motivates me a lot
- Challenge
    - 1. Does not motivate me at all
    - 2. Motivates me a bit
    - 3. Motivates me
    - 4. Motivates me quite much
    - 5. Motivates me a lot
- Excitement
    - 1. Does not motivate me at all
    - 2. Motivates me a bit
    - 3. Motivates me
    - 4. Motivates me quite much
    - 5. Motivates me a lot
- Completion
    - 1. Does not motivate me at all
    - 2. Motivates me a bit
    - 3. Motivates me
    - 4. Motivates me quite much
    - 5. Motivates me a lot
- Escapism
    - 1. Does not motivate me at all

    - 2. Motivates me a bit
    - 3. Motivates me
    - 4. Motivates me quite much
    - 5. Motivates me a lot

- You may add some other reason(s) which motivates you to play VR games.

By pressing "Submit", you accept that the data gathered in this survey can be used for research purposes. The data will be treated anonymously.


MotionInVR
www.student.oulu.fi/~ookivela/motioninvr_en.
In Finnish
Do you have HTC Vive and would you like to participate in a game study?
My name is Oona Kivelä and I am a computer science and engineering student from the University of Oulu. I am currently doing my thesis about VR games. Research focuses on the motivation for playing VR games and VR games' potential to be as an exercise form. I invite You to participate in this study!
Your task is to capture your motion data from one game session with HTC Vive, send it to me and answer a short survey. It only takes 5 to 10 minutes to answer the survey. Answers will be analyzed anonymously.
By participating in this study, you help me to graduate in these difficult times, but you also get yourself a cool motion capture program and a motion data analyzer program for later use.
From the link, you can download the MotionInVR folder to your computer. The folder contains programs for capturing the motion data and analyzing it. More detailed instructions on how to use these programs are in the same folder, a file named "Instructions_English".
Instructions:
1. Download MotionInVR to your computer.
DOWNLOAD THE FOLDER HERE



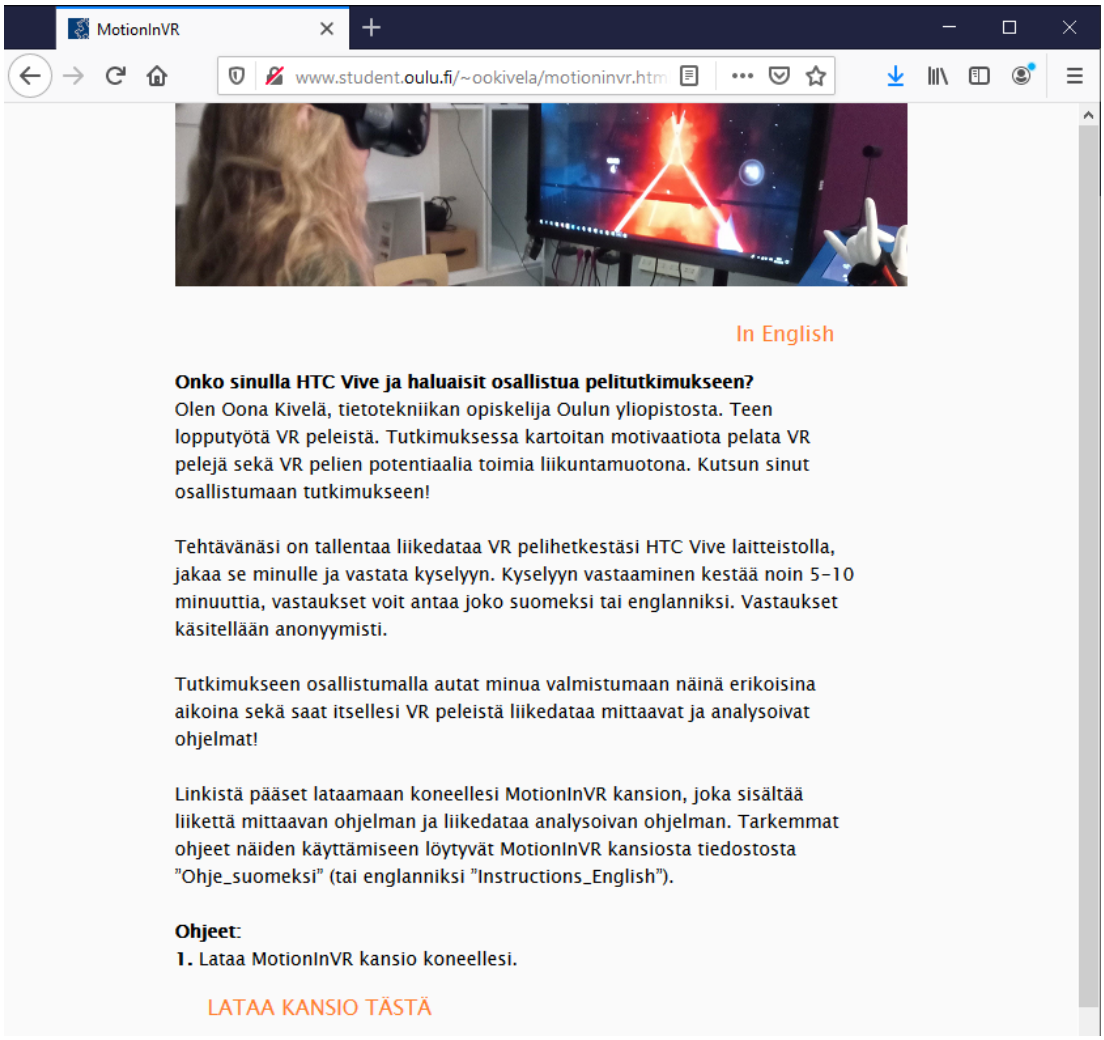
2. Open your “Downloads” folder and move the MotionInVR to any location you want.
3. Right-click the MotionInVR folder and unzip by pressing “Extract all”.
4. Navigate into MotionInVR folder via command prompt (cmd).
5. Open the VR game from which you want to save the motion data. When you are ready to start playing, write in the command prompt “hellovr_opengl.exe > vroutput.csv” and press Enter.
6. Play 15-60 minutes.
7. After you have finished the game session stop the motion data capturing by closing hellovr window by pressing the x-button on the right upper corner.
8. Compress your vroutput.csv file. Right-click the file and choose “Send to” and then choose “Compressed (zipped) folder”.
9. Open the survey, upload compressed vroutput.csv file and answer the questions.

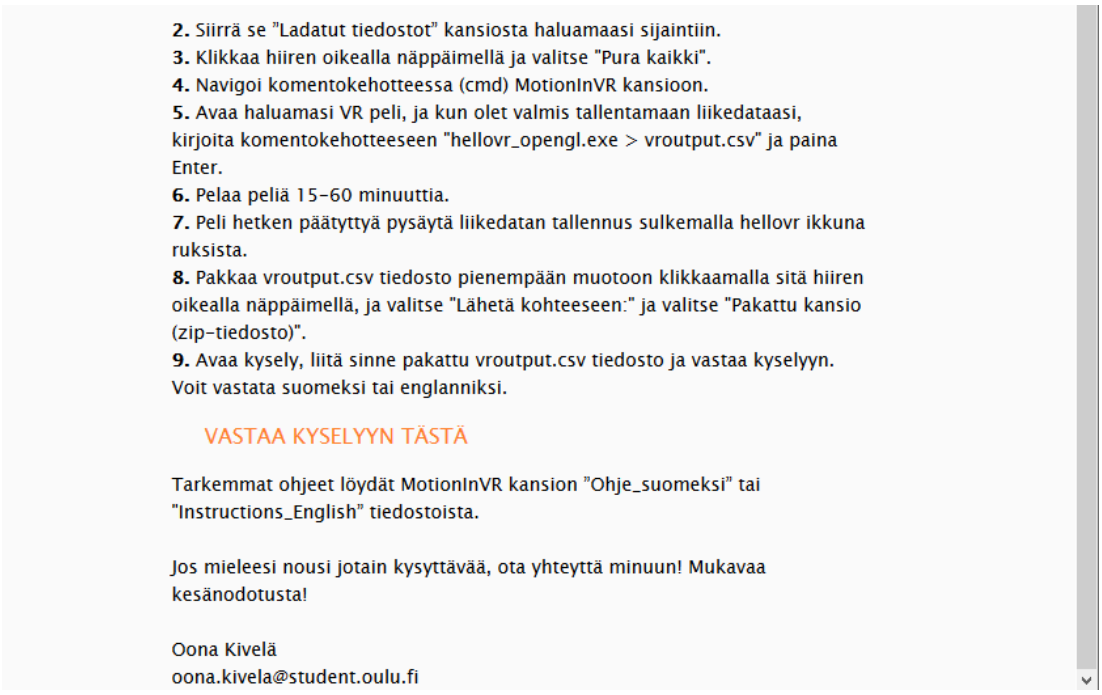
ANSWER THE SURVEY HERE

More instructions you find from the “Instructions_English” file inside the MotionInVR folder.

If you have some questions about the study, please contact me! Have a pleasant Spring and Summer!

Oona Kivelä
oona.kivela@student.oulu.fi


MotionInVR
www.student.oulu.fi/~ookivela/motioninvr.htm
In English
Onko sinulla HTC Vive ja haluaisit osallistua pelitutkimukseen?
Olen Oona Kivelä, tietotekniikan opiskelija Oulun yliopistosta. Teen lopputyötä VR peleistä. Tutkimuksessa kartoitan motivaatiota pelata VR pelejä sekä VR pelien potentiaalia toimia liikuntamuotona. Kutsun sinut osallistumaan tutkimukseen!
Tehtävänäsi on tallentaa liikedataa VR pelihetkestäsi HTC Vive laitteistolla, jakaa se minulle ja vastata kyselyyn. Kyselyyn vastaaminen kestää noin 5-10 minuuttia, vastaukset voit antaa joko suomeksi tai englanniksi. Vastaukset käsitellään anonyymisti.
Tutkimukseen osallistumalla autat minua valmistumaan näinä erikoisina aikoina sekä saat itsellesi VR peleistä liikedataa mittaavat ja analysoivat ohjelmat!
Linkistä pääset lataamaan koneellesi MotionInVR kansion, joka sisältää liikettä mittaavan ohjelman ja liikedataa analysoivan ohjelman. Tarkemmat ohjeet näiden käyttämiseen löytyvät MotionInVR kansiosta tiedostosta ”Ohje_suomeksi” (tai englanniksi ”Instructions_English”).
Ohjeet:
1. Lataa MotionInVR kansio koneellesi.
LATAA KANSIO TÄSTÄ



2. Siirrä se "Ladatut tiedostot" kansiosta haluamaasi sijaintiin.
3. Klikkaa hiiren oikealla näppäimellä ja valitse "Pura kaikki".
4. Navigoi komentokehotteessa (cmd) MotionInVR kansioon.
5. Avaa haluamasi VR peli, ja kun olet valmis tallentamaan liikedataasi, kirjoita komentokehotteeseen "hellovr_opengl.exe > vroutput.csv" ja paina Enter.
6. Pelaa peliä 15–60 minuuttia.
7. Peli hetken päätyttyä pysäytä liikedatan tallennus sulkemalla hellovr ikkuna ruksista.
8. Pakkaa vroutput.csv tiedosto pienempään muotoon klikkaamalla sitä hiiren oikealla näppäimellä, ja valitse "Lähetä kohteeseen:" ja valitse "Pakattu kansio (zip-tiedosto)".
9. Avaa kysely, liitä sinne pakattu vroutput.csv tiedosto ja vastaa kyselyyn. Voit vastata suomeksi tai englanniksi.

VASTAA KYSELYYN TÄSTÄ

Tarkemmat ohjeet löydät MotionInVR kansion "Ohje_suomeksi" tai "Instructions_English" tiedostoista.

Jos mieleesi nousi jotain kysyttävää, ota yhteyttä minuun! Mukavaa kesänodotusta!

Oona Kivelä
oona.kivela@student.oulu.fi